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Acronyms	
BMP	Best Management Practices
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EIS	Environmental Impact Statement
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
IBWC	International Boundary Water Commission
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
NOAA	National Oceanic and Atmospheric Administration
NTU	Nephalometric Turbidity Unit
NWS	National Weather Service
TDS	Total Dissolved Solids
URGWOPS	Upper Rio Grande Water Operations
USACE	US Army Corps of Engineers
USEPA	US Environmental Protection Agency
USGS	US Geological Survey
WQ	Water Quality
WQR	Water Quality Reach
WQRT	Water Quality Resource Team

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1.0 GENERAL DESCRIPTION OF THE UPPER RIO GRANDE BASIN

The Rio Grande is an important water resource for residents of and the environment in Colorado, New Mexico, Texas, and the Republic of Mexico. Rio Grande water is repeatedly diverted for irrigation and returned to the river channel directly or through drains, impounded by reservoirs, and lost to evaporation, transpiration, and consumption. Irrigation is the biggest use of Rio Grande water in both the United States and Mexico, accounting for 89 percent of all water taken from the river. Municipal use accounts for 8 percent, and other uses account for 3 percent (Levings et al. 1998). As a result of these uses, as well as natural conditions and processes, water quality is altered and streamflow decreases in the downstream direction throughout most of the Basin (Healy 1997). The Rio Grande becomes a losing stream downstream of the Otowi Gage, with inflows only from ephemeral or intermittent streams and arroyos that flow during snowmelt and storm runoff, from groundwater, and from return flow from ditches and canals.

Reservoirs are the primary tool for managing water resources in the western and southwestern United States, and both large and small reservoirs contribute to altering the natural flow of water within the Rio Grande Basin. Eighteen reservoirs in the Rio Grande watershed have storage capacities greater than 5,000 acre-feet (Moore and Anderholm 2002), holding water for irrigation and/or public use.

The natural variability of surface water quality within the upper Rio Grande Basin can be attributed to a variety of watershed characteristics and hydrologic processes. These processes include the dynamic balance between the chemical composition of surface water, including tributary inflow and groundwater interaction (hyporheic zone), precipitation, surrounding geology, nutrient uptake, erosive capability of the channel and surrounding land, and evapotranspiration. Anthropogenic activities such as forestry, agriculture, industrial and municipal activities, urban development, road construction, and storm water runoff contribute sediment, nutrients, and other pollutants to the system. These land uses may contribute to deterioration in the surface water quality of the Rio Grande (Levings et al. 1998). Specifically, urban areas add volatile compounds, organic chemicals, and pesticides via wastewater effluent and runoff; agricultural areas contribute chemicals from the application of fertilizers and pesticides in return flows and overland flow; mining adds trace elements via mine tailings and can alter the quantity of transported sediment; atmospheric deposition contributes nitrates (HNO_3) and phosphates (H_3O_4P) and additional pollutants carried in from outlying distances; and the use and reuse of water increase dissolved solid concentrations as a result of evapotranspiration.

Water quality is further impacted by the emplacement of dams and the presence and operation of reservoirs. How these facilities are managed can significantly impact river systems in the arid to semi-arid environments of the Southwest, where water is a seasonal and often scarce resource. Reservoir operations affect water quality by altering water chemistry, natural flow variation, and the transport of sediments, nutrients, and contaminants. Within the Rio Grande watershed, these impacts occur in three primary ways. (1) Reservoirs regulate the downstream flow of sediments, nutrients, and contaminants contributed by groundwater, tributaries, and overland flow sources. Diminished water velocity in reservoirs causes nutrients and suspended sediments to settle, thus decreasing the natural nutrients and sediments in the system. (2) Reservoirs and dams create a unique physical and chemical environment that affects nutrient cycling within the reservoirs, and ultimately may impact riverine environments upstream and downstream of the reservoir. For example, contaminants and nutrients may be sequestered within the sediment of the reservoir, thus decreasing concentrations in downstream reaches; and pollutants may be transformed into alternative forms (e.g., mercury [Hg] to methylmercury (+1) ion $[CH^3HG^+ +]$, sulfate $[O^4S^{-2}-_2]$ to sulfide $[S^{-2}-_2]$), discharged unchanged; or accumulated either directly or through food-chain transfers by plants, fish and other aquatic organisms, and wildlife. (3) Reservoirs commonly alter the natural temperature regime downstream. Water released from the depths of a reservoir may produce cooler surface temperatures downstream, altering natural conditions that species have become adapted to. Conversely, water released from higher levels in a reservoir may increase surface temperature downstream. The high heat capacity of the stored reservoir water thus alters the natural cycle and modifies water quality constituents that are influenced by or dependent on water temperature.

The effects of reservoirs on water quality dissipate as flows continue downstream. With distance from the reservoir, the impacts of tributaries, overland flow, atmospheric conditions, adjacent land use, and surrounding geology on local water quality become greater. For example, as water travels downstream after being released from a reservoir, temperature and dissolved oxygen, as well as other constituents, quickly equilibrate with ambient atmospheric conditions. The specific manner in which these changes occur depends on air temperature, storm or snowmelt runoff, land use, and factors such as turbulence within a river reach.

1.1 Regulatory Environment

The Clean Water Act (as amended) and various state regulations such as the New Mexico Water Quality Act of 1978 require the development of water quality standards to protect public and private interests, wildlife, and the quality of waters. In addition, Native American Pueblos within the Rio Grande Basin maintain their own water quality standards and regulations. The project area includes three states (Colorado, New Mexico, and Texas), 11 Native American tribes or pueblos (Taos, San Juan, Santa Clara, San Ildefonso, Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia, Isleta, and Jicarilla Apache), and various federal and local agencies with distinct jurisdictional boundaries and concerns directly related to water quality. Water quality within the upper Rio Grande Basin is regulated by the standards of each of the three states, of the Rio Grande Compact of 1938, and of four of the Pueblos (San Juan, Santa Clara, Sandia, and Isleta). At the time of this report, the other Pueblos have either not developed specific water quality standards or the U.S. Environmental Protection Agency (EPA) had not yet adopted their standards.

Each regulatory entity has developed numeric standards, narrative (general) standards, and antidegradation statements to ensure the quality of water. Numeric standards are for water constituents that can be quantified and for which accurate background conditions have been established to provide a threshold for assessing water quality. Narrative standards are used when constituent levels cannot be measured or when background conditions are unknown. Narrative standards are not quantifiable; they provide general guidance to ensure that factors affecting water quality do not exceed baseline conditions. Antidegradation statements declare that existing uses of water must be maintained and protected. Through these statements, states must protect current uses and prevent waters from deteriorating. States and Tribes also use antidegradation statements to protect against hydrologic and physical alterations. They can be applied to all waters, with or without numeric or narrative standards, to ensure that waters are not degraded beyond their current condition without specific authorization. When water bodies are not in compliance with any of these standards, they are subject to enforcement actions under Clean Water Act sections 303(d) and 305(b).

1.2 Reach Descriptions

For the Upper Rio Grande Water Operations (URGWOPS) Environmental Impact Statement (EIS), 17 unique river reaches were defined based on changes in channel geomorphology and hydrology (see Map 1-1 of EIS). The Water Quality Resource Team (WQRT) of the URGWOPS Review and EIS evaluated the applicable federal, state, tribal, and compact standards and jurisdictional boundaries within the 17 reaches and defined 42 unique water quality assessment subreaches (WQRs) to address conditions specific to those portions of the Rio Grande (Table WQ1). The boundaries of these reaches were set either where a change in water quality regulations or land governance occurred or where waters entered or left a reservoir. The following section describes the boundaries of each reach and defines the standards that apply to that reach.

Table M-1. Water Quality Subreach Numbers and Boundaries as Defined by the Water Quality Resource Team of the Upper Rio Grande Water Operations Review and EIS

WQR	REACH NAME	WATER QUALITY JURISDICTIONAL AUTHORITY
1.1	Rio Grande upstream of Closed Basin Project	State of Colorado
1.2	Closed Basin project discharge	State of Colorado/Rio Grande Compact
1.3	Rio Grande Closed Basin discharge to Conejos River	State of Colorado
1.4	Rio Grande Conejos confluence to New Mexico state line	State of Colorado
2.1	Conejos River inflow to Platoro Reservoir	State of Colorado
2.2	Platoro Reservoir	State of Colorado
2.3	Conejos River below Platoro Reservoir	State of Colorado
3.1	Rio Grande Colorado state line to Taos Pueblo	State of New Mexico
3.2	Rio Grande Taos Pueblo	State of New Mexico / Taos Pueblo
3.3	Rio Grande Taos Pueblo to Velarde	State of New Mexico
4.1	Rio Grande Velarde to San Juan Pueblo	State of New Mexico
4.2	Rio Grande on San Juan Pueblo to the Rio Chama	San Juan Pueblo
5.1	Rio Chama above Heron Reservoir outflow	State of New Mexico
5.2	Heron Reservoir	State of New Mexico
5.3	Rio Chama Heron Reservoir to El Vado Reservoir	State of New Mexico
6.1	El Vado Reservoir	State of New Mexico
6.2	Rio Chama El Vado Reservoir to Abiquiu Reservoir	State of New Mexico
7.1	Abiquiu Reservoir	State of New Mexico
7.2	Rio Chama Abiquiu Reservoir to San Juan Pueblo	State of New Mexico
7.3	Rio Chama on San Juan Pueblo	San Juan Pueblo
8.0.a	Rio Grande below Rio Chama confluence on San Juan Pueblo	San Juan Pueblo
8.0.b	Rio Grande San Juan Pueblo to Santa Clara Pueblo	State of New Mexico
8.0.c	Rio Grande on Santa Clara Pueblo	Santa Clara Pueblo
8.0.d	Rio Grande Santa Clara Pueblo to Otowi	San Ildefonso Pueblo / State of New Mexico
9.0	Rio Grande Otowi Gage to Cochiti Reservoir	San Ildefonso, Cochiti Pueblos / State of New Mexico
10.1	Cochiti Reservoir	Cochiti Pueblo / State of New Mexico
10.2	Rio Grande–Cochiti Reservoir to Jemez River	Cochiti, Santo Domingo, San Felipe Pueblos
10.3	Rio Grande–Jemez confluence to Bernalillo (Hwy 550)	San Felipe Pueblo / State of New Mexico
11.1	Jemez River inflow	Santa Ana Pueblo / State of New Mexico
11.2	Jemez Reservoir	Santa Ana Pueblo / State of New Mexico
11.3	Jemez River below Jemez Reservoir to Rio Grande	Santa Ana Pueblo / State of New Mexico
12.0.a	Rio Grande on Sandia Pueblo	Sandia Pueblo
12.0.b	Rio Grande Sandia Pueblo to Isleta Pueblo	State of New Mexico
12.0.c	Rio Grande on Isleta Pueblo	Isleta Pueblo
13.0	Rio Grande Isleta Diversion Dam to Rio Puerco	State of New Mexico
14.0	Rio Grande Rio Puerco to Elephant Butte Reservoir	State of New Mexico
15.1	Elephant Butte Reservoir	State of New Mexico
15.2	Rio Grande Elephant Butte to Caballo Reservoir	State of New Mexico
16.1	Caballo Reservoir	State of New Mexico
16.2	Caballo Reservoir to TX State Line	State of New Mexico
17.1	Rio Grande TX State Line to America Diversion Dam	State of Texas/ Republic of Mexico
17.2	Rio Grande American Diversion to Ft. Quitman TX	State of Texas/ Republic of Mexico

1.2.1 Applicable Standards for Water Quality Reaches (WQR)

WQR 1.1

MAINSTEM OF THE RIO GRANDE FROM A POINT IMMEDIATELY ABOVE THE CONFLUENCE WITH WILLOW CREEK TO THE RIO GRANDE/ALAMOSA COUNTY LINE

Colorado Standards:

A. Designated Uses: coldwater aquatic life 1, recreation 1, water supply, agriculture

B. Standards:

(1) Physical and Biological: Temperature, 20^{o} C, DO = 6.0 mg/L (7.0 mg/L during fish spawning), pH = 6.5-9.0, fecal coliform = 200/100 mL

(2) Metals: Arsenic (As) (acute, total recoverable) = 50 ug/L, Mercury (Hg) (chronic, total recoverable) = 0.01 ug/L

(3) Narrative Standards: Except where authorized by permits, Best Management Practices (BMPs), 401 certifications, or plans of operation approved by the Division or other applicable agencies, state surface waters shall be free from substances attributable to human-caused point source or nonpoint source discharge in amounts, concentrations or combinations which:

(a) for all surface waters except wetlands;

(i) can settle to form bottom deposits detrimental to the beneficial uses. Depositions are stream bottom buildup of materials which include but are not limited to anaerobic sludges, mine slurry or tailings, silt, or mud; or

(ii) form floating debris, scum, or other surface materials sufficient to harm existing beneficial uses; or

(iii) produce color, odor, or other conditions in such a degree as to create a nuisance or harm existing beneficial uses or impart any undesirable taste to significant edible aquatic species or to the water; or

(iv) are harmful to the beneficial uses or toxic to humans, animals, plants, or aquatic life; or

(v) produce a predominance of undesirable aquatic life; or

(vi) cause a film on the surface or produce a deposit on shorelines;

WQR 1.2

CLOSED BASIN PROJECT DISCHARGE

Rio Grande Compact Standards:

A. Standards:

(1) The Rio Grande Compact, which provides for apportionment of the flows of the Rio Grande among the concerned states, recognized the potentialities for delivery of Closed Basin waters to the Rio Grande and provides that Colorado shall be credited with the amount of such water delivered to the compact station at Lobatos, CO if the proportion of sodium ions in the salvaged water shall be less than 45 percent of the total positive ions when the total dissolved solids in such water exceeds 350 parts per million.

WQR 1.3, 1.4

MAINSTEM OF THE RIO GRANDE FROM THE RIO GRANDE/ALAMOSA COUNTY LINE TO THE OLD STATE BRIDGE EAST OF LOBATOS (CONEJOS COUNTY ROAD G)

Colorado Standards:

A. Designated Uses: warmwater aquatic life 1, recreation 1, agriculture

B. Standards:

(1) Physical and Biological: Temperature, 20° C, DO = 6.0 mg/L, pH = 6.5-9.0, fecal coliform = 200/100 mL

(2) Metals: As (acute, total recoverable) = 100 ug/L, Hg (chronic, total recoverable) = 0.01 ug/L

(3) Narrative Standards: Except where authorized by permits, BMPs, 401 certifications, or plans of operation approved by the Division or other applicable agencies, state surface waters shall be free from substances attributable to human-caused point source or nonpoint source discharge in amounts, concentrations or combinations which:

(a) for all surface waters except wetlands;

(i) can settle to form bottom deposits detrimental to the beneficial uses. Depositions are stream bottom buildup of materials which include but are not limited to anaerobic sludges, mine slurry or tailings, silt, or mud; or

(ii) form floating debris, scum, or other surface materials sufficient to harm existing beneficial uses; or

(iii) produce color, odor, or other conditions in such a degree as to create a nuisance or harm existing beneficial uses or impart any undesirable taste to significant edible aquatic species or to the water; or

(iv) are harmful to the beneficial uses or toxic to humans, animals, plants, or aquatic life; or

(v) produce a predominance of undesirable aquatic life; or

(vi) cause a film on the surface or produce a deposit on shorelines;

WQR 1.4

MAINSTEM OF THE RIO GRANDE FROM THE OLD STATE BRIDGE EAST OF LOBATOS (CONEJOS COUNTY ROAD G) TO THE COLORADO/NEW MEXICO BORDER

Colorado Standards:

A. Designated Uses: coldwater aquatic life 1, recreation 1, agriculture

B. Standards:

(1) Physical and Biological: Temperature, 20° C, DO = 6.0 mg/L (7.0 mg/L during fish spawning), pH = 6.5-9.0, fecal coliform = 200/100 mL

(2) Metals: As (acute, total recoverable) = 100 ug/L, Hg (chronic, total recoverable) = 0.01 ug/L

(3) Narrative Standards: Except where authorized by permits, BMPs, 401 certifications, or plans of operation approved by the Division or other applicable agencies, state surface waters shall be free from substances attributable to human-caused point source or nonpoint source discharge in amounts, concentrations or combinations which:

(a) for all surface waters except wetlands;

(i) can settle to form bottom deposits detrimental to the beneficial uses. Depositions are stream bottom buildup of materials which include but are not limited to anaerobic sludges, mine slurry or tailings, silt, or mud; or

(ii) form floating debris, scum, or other surface materials sufficient to harm existing beneficial uses; or

(iii) produce color, odor, or other conditions in such a degree as to create a nuisance or harm existing beneficial uses or impart any undesirable taste to significant edible aquatic species or to the water; or

(iv) are harmful to the beneficial uses or toxic to humans, animals, plants, or aquatic life; or

(v) produce a predominance of undesirable aquatic life; or

(vi) cause a film on the surface or produce a deposit on shorelines;

WQR 2.1, 2.2, 2.3

MAINSTEM OF THE CONEJOS RIVER INCLUDING ALL TRIBUTARIES, WETLANDS, LAKES, AND RESERVOIRS FROM SOURCE TO IMMEDIATELY ABOVE THE CONFLUENCE WITH FOX CREEK; AND, MAINSTEM OF THE CONEJOS RIVER FROM A POINT IMMEDIATELY ABOVE THE CONFLUENCE WITH FOX CREEK TO THE CONFLUENCE WITH THE SAN ANTONIO RIVER, CO.

Colorado Standards:

A. Designated Uses: coldwater aquatic life 1 and 2, recreation 1, water supply, agriculture

B. Standards:

(1) Physical and Biological: Temperature, 20^{o} C, DO = 6.0 mg/L (7.0 mg/L during fish spawning), pH = 6.5-9.0, fecal coliform = 200/100 mL

(2) Metals: As (acute, total recoverable) = 50 ug/L, Hg (chronic, total recoverable) = 0.01 ug/L

(3) Narrative Standards: Except where authorized by permits, BMPs, 401 certifications, or plans of operation approved by the Division or other applicable agencies, state surface waters shall be free from substances attributable to human-caused point source or nonpoint source discharge in amounts, concentrations or combinations which:

(a) for all surface waters except wetlands;

(i) can settle to form bottom deposits detrimental to the beneficial uses. Depositions are stream bottom buildup of materials which include but are not limited to anaerobic sludges, mine slurry or tailings, silt, or mud; or

(ii) form floating debris, scum, or other surface materials sufficient to harm existing beneficial uses; or

(iii) produce color, odor, or other conditions in such a degree as to create a nuisance or harm existing beneficial uses or impart any undesirable taste to significant edible aquatic species or to the water; or

(iv) are harmful to the beneficial uses or toxic to humans, animals, plants, or aquatic life; or

(v) produce a predominance of undesirable aquatic life; or

(vi) cause a film on the surface or produce a deposit on shorelines;

WQR 2.3

MAINSTEM OF THE CONEJOS RIVER FROM THE CONFLUENCE WITH THE SAN ANTONIO RIVER TO THE CONFLUENCE WITH THE RIO GRANDE

Colorado Standards:

A. Designated Uses: warmwater aquatic life 2, recreation 2, agriculture

B. Standards:

(1) Physical and Biological: Temperature, 25^{o} C, DO = 5.0 mg/L, pH = 6.5-9.0, fecal coliform = 200/100 mL

(2) Metals: As (acute, total recoverable) = 100 ug/L, Hg (chronic, total recoverable) = Table Value Standard

(4) Narrative Standards: Except where authorized by permits, BMPs, 401 certifications, or plans of operation approved by the Division or other applicable agencies, state surface waters shall be free from substances attributable to human-caused point source or nonpoint source discharge in amounts, concentrations or combinations which:

(a) for all surface waters except wetlands;

- (i) can settle to form bottom deposits detrimental to the beneficial uses. Depositions are stream bottom buildup of materials which include but are not limited to anaerobic sludges, mine slurry or tailings, silt, or mud; or
- (ii) form floating debris, scum, or other surface materials sufficient to harm existing beneficial uses; or
- (iii) produce color, odor, or other conditions in such a degree as to create a nuisance or harm existing beneficial uses or impart any undesirable taste to significant edible aquatic species or to the water; or
- (iv) are harmful to the beneficial uses or toxic to humans, animals, plants, or aquatic life; or
- (v) produce a predominance of undesirable aquatic life; or
- (vi) cause a film on the surface or produce a deposit on shorelines;

WQR 3.1, 3.2

RIO GRANDE BASIN – THE MAIN STEM OF THE RIO GRANDE FROM TAOS JUNCTION BRIDGE UPSTREAM TO THE NEW MEXICO-COLORADO LINE

New Mexico Standards (20.6.4.122):

A. Designated Uses: coldwater fishery, fish culture, irrigation, livestock watering, wildlife habitat, and primary contact

B. Standards:

- **(1)** In any single sample: pH shall be within the range of 6.6 to 8.8, temperature shall not exceed 20°C (68°F), and turbidity shall not exceed 50 Nephelometric Turbidity Units (NTU). The use-specific numeric standards set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.
- **(2)** Narrative standards are those set forth in section 20.6.4.12 of the State of New Mexico Standards for Interstate and Intrastate Surface Waters. These include, but are not limited to:
  - i. Bottom Deposits – Surface waters of the State shall be free of water contaminants from other than natural causes that will settle and damage or impair the normal growth, function, or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.
  - ii. Plant Nutrients – Plant nutrients from other than natural causes shall not be present in concentrations, which will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the state.

WQR 3.3, 4.1, 4.2, 8.0b, 8.0d, 9.0

RIO GRANDE BASIN – THE MAIN STEM OF THE RIO GRANDE FROM THE HEADWATERS OF COCHITI RESERVOIR UPSTREAM TO TAOS JUNCTION BRIDGE

New Mexico Standards (20.6.4.114):

A. Designated Uses: irrigation, livestock watering, wildlife habitat, marginal coldwater fishery, primary contact, and warmwater fishery.

B. Standards:

- **(1)** In any single sample: pH shall be within the range of 6.6 to 9.0, temperature shall not exceed 22°C (71.6°F), and turbidity shall not exceed 50 NTU. The use-specific numeric standards set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.
- **(2)** The monthly geometric mean of fecal coliform bacteria shall not exceed 200/100 mL; no single sample shall exceed 400/100 mL. (see Subsection B of 20.6.4.13 NMAC).

(3) At mean monthly flows above 100 cfs, the monthly average concentration for: TDS shall not exceed 500 mg/L, sulfate shall not exceed 150 mg/L, and chloride (Cl^-) shall not exceed 25 mg/L.

(4) Narrative standards are those set forth in section 20.6.4.12 of the State of New Mexico Standards for Interstate and Intrastate Surface Waters. These include, but are not limited to:

i. Bottom Deposits – Surface waters of the State shall be free of water contaminants from other than natural causes that will settle and damage or impair the normal growth, function, or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.

ii. Plant Nutrients – Plant nutrients from other than natural causes shall not be present in concentrations, which will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the state.

WQR 5.1, 5.3

RIO GRANDE BASIN – ALL PERENNIAL REACHES OF TRIBUTARIES TO THE RIO CHAMA ABOVE ABIQUIU DAM EXCEPT THE RIO GALLINA AND THE RIO PUERCO DE CHAMA NORTH OF STATE HIGHWAY 96 AND THE MAIN STEM OF THE RIO CHAMA FROM THE HEADWATERS OF EL VADO RESERVOIR UPSTREAM TO THE NEW MEXICO-COLORADO LINE

New Mexico Standards (20.6.4.119):

A. Designated Uses: domestic water supply, fish culture, high quality coldwater fishery, irrigation, livestock watering, wildlife habitat, and secondary contact.

B. Standards:

(1) In any single sample; conductivity shall not exceed 500 umhos (1,000 umhos for Coyote creek), pH shall be within the range of 6.6 to 8.8, temperature shall not exceed 20°C (68°F), and turbidity shall not exceed 25 NTU. The use-specific numeric standards set forth in 20.6.4.13 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL (see Subsection B of 20.6.4.13 NMAC).

(3) Narrative standards are those set forth in section 20.6.4.12 of the State of New Mexico Standards for Interstate and Intrastate Surface Waters. These include, but are not limited to:

i. Bottom Deposits – Surface waters of the State shall be free of water contaminants from other than natural causes that will settle and damage or impair the normal growth, function, or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.

ii. Plant Nutrients – Plant nutrients from other than natural causes shall not be present in concentrations, which will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the state.

WQR 5.2, 6.1

RIO GRANDE BASIN – EL VADO AND HERON RESERVOIRS

New Mexico Standards (20.6.4.120):

A. Designated Uses: irrigation storage, livestock watering, wildlife habitat, primary contact, and coldwater fishery.

B. Standards:

(1) At any sampling site: pH shall be within the range of 6.6 to 8.8, temperature shall not exceed 20°C (68°F), and turbidity shall not exceed 25 NTU. The use-specific numeric standards set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL (see Subsection B of 20.6.4.13 NMAC).

(3) Narrative standards are those set forth in section 20.6.4.12 of the State of New Mexico Standards for Interstate and Intrastate Surface Waters. These include, but are not limited to:

i. Bottom Deposits – Surface waters of the State shall be free of water contaminants from other than natural causes that will settle and damage or impair the normal growth, function, or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.

ii. Plant Nutrients – Plant nutrients from other than natural causes shall not be present in concentrations, which will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the state.

iii. When changes in dissolved oxygen, temperature, dissolved solids, sediment or turbidity in a water of the State is attributable to natural causes or the reasonable operation of irrigation and flood control facilities that are not subject to federal or state water pollution control permitting, numerical standards for temperature, dissolved solids content, dissolved oxygen, sediment or turbidity adopted under the Water Quality Act do not apply. The foregoing provision does not include major reconstruction of storage dams or diversion dams except for emergency actions necessary to protect health and safety of the public, or discharges from municipal separate storm sewers.

WQR 6.2

RIO GRANDE BASIN – THE RIO CHAMA FROM THE HEADWATERS OF ABIQUIU RESERVOIR UPSTREAM TO EL VADO RESERVOIR AND THE RIO GALLINA AND RIO PUERCO DE CHAMA NORTH OF STATE HIGHWAY 96

New Mexico Standards (20.6.4.118)

A. Designated Uses: irrigation, livestock watering, wildlife habitat, primary contact, coldwater fishery, and warmwater fishery

B. Standards:

(1) In any single sample: pH shall be within the range of 6.6 to 8.8, and temperature shall not exceed 26°C (78.8°F). The use-specific numeric standards set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) The monthly geometric mean of fecal coliform bacteria shall not exceed 200/100mL; no single sample shall exceed 400/100mL (see Subsection B of 20.6.4.13 NMAC)

(3) Narrative standards are those set forth in section 20.6.4.12 of the State of New Mexico Standards for Interstate and Intrastate Surface Waters. These include, but are not limited to:

i. Bottom Deposits – Surface waters of the State shall be free of water contaminants from other than natural causes that will settle and damage or impair the normal growth, function, or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.

ii. Plant Nutrients – Plant nutrients from other than natural causes shall not be present in concentrations, which will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the state.

iii. Turbidity – Turbidity attributable to other than natural causes shall not reduce light transmission to the point that the normal growth, function, or reproduction of aquatic life is impaired or that will cause substantial visible contrast with the natural appearance of the water.

WQR 7.1

RIO GRANDE BASIN – ABIQUIU RESERVOIR

New Mexico Standards (20.6.4.117):

A. Designated Uses: irrigation storage, livestock watering, wildlife habitat, primary contact, coldwater fishery, and warm water fishery.

B. Standards:

(1) At any sampling site: pH shall be within the range of 6.6 to 8.8, and temperature shall not exceed 25°C (77°F). The use specific numeric standards set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL (see Subsection B of 20.6.4.13 NMAC)

(3) Narrative standards are those set forth in section 20.6.4.12 of the State of New Mexico Standards for Interstate and Intrastate Surface Waters. These include, but are not limited to:

i. Bottom Deposits – Surface waters of the State shall be free of water contaminants from other than natural causes that will settle and damage or impair the normal growth, function, or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.

ii. Plant Nutrients – Plant nutrients from other than natural causes shall not be present in concentrations, which will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the state.

iii. Turbidity – Turbidity attributable to other than natural causes shall not reduce light transmission to the point that the normal growth, function, or reproduction of aquatic life is impaired or that will cause substantial visible contrast with the natural appearance of the water.

iv. When changes in dissolved oxygen, temperature, dissolved solids, sediment or turbidity in a water of the state is attributable to natural causes or the reasonable operation of irrigation and flood control facilities that are not subject to federal or state water pollution control permitting, numerical standards for temperature, dissolved solids content, dissolved oxygen, sediment or turbidity adopted under the Water Quality Act do not apply. The foregoing provision does not include major reconstruction of storage dams or diversion dams except for emergency actions necessary to protect health and safety of the public, or discharges from municipal separate storm sewers.

WQR 7.2

THE RIO CHAMA FROM ITS MOUTH ON THE RIO GRANDE UPSTREAM TO ABIQUIU RESERVOIR, THE RIO TUSAS, THE RIO OJO CALIENTE, ABIQUIU CREEK, AND EL RITO CREEK BELOW THE TOWN OF EL RITO

New Mexico Standards (20.6.4.116):

A. Designated Uses: irrigation, livestock watering, wildlife habitat, coldwater fishery, warmwater fishery, and secondary contact.

B. Standards:

(1) In any single sample: pH shall be within the range of 6.6 to 8.8, and temperature shall not exceed 31°C (87.8°F). The use specific numeric standards set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) The monthly geometric mean of fecal coliform bacteria shall not exceed 1,000/100 mL; no single sample shall exceed 2,000/100 mL (see Subsection B of 20.6.4.13 NMAC)

(3) Narrative standards are those set forth in section 20.6.4.12 of the State of New Mexico Standards for Interstate and Intrastate Surface Waters. These include, but are not limited to:

  i. Bottom Deposits – Surface waters of the State shall be free of water contaminants from other than natural causes that will settle and damage or impair the normal growth, function, or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.

  ii. Plant Nutrients – Plant nutrients from other than natural causes shall not be present in concentrations, which will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the state.

  iii. Turbidity – Turbidity attributable to other than natural causes shall not reduce light transmission to the point that the normal growth, function, or reproduction of aquatic life is impaired or that will cause substantial visible contrast with the natural appearance of the water.

WQR 7.3

SEGMENT OF THE RIO CHAMA THAT PASSES THROUGH SAN JUAN PUEBLO

San Juan Pueblo Standards:

A. Designated Uses: coldwater fishery, warmwater fishery, primary contact ceremonial, primary contact recreational, secondary contact recreational, agriculture, industrial water supply

B. Standards:

(1) Dissolved oxygen = 6mg/L, fecal coliform = 100/100 mL (geometric mean) or 200/100 mL (single sample), temperature = 20^{o} C, pH = 6.5-8.5, turbidity = 25 NTU, As = 20.5 ug/L, Hg (fish consumption) = 0.051ug/L

(2) Narrative standards include, but are not limited to:

  i. Stream Bottom Deposits – Surface waters shall be free from water contaminants from other than natural causes that may settle and have a deleterious effect on the aquatic biota or that will significantly alter the physical or chemical properties of the water or the bottom sediments.

  ii. Nuisance Conditions – Plant nutrients or other substances stimulating algal growth from other than natural causes shall not be present in concentrations that produce objectionable algal densities or nuisance aquatic vegetation, or that result in a dominance of nuisance species instream, or that cause nuisance conditions in any other fashion. Phosphorous (P) and nitrogen (N) concentrations shall not reach levels, which result in man-induced eutrophication problems. Total P shall not exceed 100 ug/L instream or 50 ug/L in lakes in reservoirs except waters highly laden with natural silts or color which reduce the penetration of light needed for photosynthesis, or in other waters where it can be demonstrated that algal production will not interfere with or adversely affect designated and other attainable uses.

  iii. Salinity/Mineral Quality – (TDS, chlorides, and sulfates) existing mineral quality shall not be altered by municipal, industrial, or instream activities, or other water discharges so as to interfere with the designated or attainable uses for a water body. An increase of more than 1/3 over naturally-occurring levels shall not be permitted. Numeric criteria for chlorides at 230 mg/L, for sulfates at 250 mg/L, and for TDS at 500 mg/L shall not be exceeded.

WQR 8.0a

SEGMENT OF THE RIO GRANDE THAT PASSES THROUGH SAN JUAN PUEBLO

San Juan Pueblo Standards:

A. Designated Uses: coldwater fishery, warmwater fishery, primary contact ceremonial, primary contact recreational, secondary contact recreational, agriculture, industrial water supply

B. Standards:

- **(1)** Dissolved oxygen = 6mg/L, fecal coliform = 100/100 mL (geometric mean) or 200/100 mL (single sample), temperature = 20^o C, pH = 6.5-8.5, turbidity = 25 NTU, As = 20.5 ug/L, Hg (fish consumption) = 0.051ug/L
- **(2)** Narrative standards include, but are not limited to:
  - i. Stream Bottom Deposits – Surface waters shall be free from water contaminants from other than natural causes that may settle and have a deleterious effect on the aquatic biota or that will significantly alter the physical or chemical properties of the water or the bottom sediments.
  - ii. Nuisance Conditions – Plant nutrients or other substances stimulating algal growth from other than natural causes shall not be present in concentrations that produce objectionable algal densities or nuisance aquatic vegetation, or that result in a dominance of nuisance species instream, or that cause nuisance conditions in any other fashion. Phosphorous and nitrogen concentrations shall not reach levels, which result in man-induced eutrophication problems. Total P shall not exceed 100 ug/L instream or 50 ug/L in lakes in reservoirs except waters highly laden with natural silts or color which reduce the penetration of light needed for photosynthesis, or in other waters where it can be demonstrated that algal production will not interfere with or adversely affect designated and other attainable uses.
  - iii. Salinity/Mineral Quality – (TDS, chlorides, and sulfates) existing mineral quality shall not be altered by municipal, industrial, or instream activities, or other water discharges so as to interfere with the designated or attainable uses for a water body. An increase of more than 1/3 over naturally-occurring levels shall not be permitted. Numeric criteria for chlorides at 230 mg/L, for sulfates at 250 mg/L, and for TDS at 500 mg/L shall not be exceeded.

WQR 8.0c

SEGMENT OF THE RIO GRANDE THAT PASSES THROUGH SANTA CLARA PUEBLO

Santa Clara Pueblo Standards:

A. Designated Uses: marginal coldwater fishery, warmwater fishery, irrigation, livestock and wildlife, primary contact

B. Standards:

- **(1)** Dissolved oxygen = 6mg/L, fecal coliform = 200/100 mL, temperature = 25^o C, pH = 6.6-8.8, turbidity = 25 NTU, TDS = 500 mg/L, As = 360 ug/L
- **(2)** Narrative standards include, but are not limited to:
  - i. Stream Bottom Deposits – Surface waters shall be free from water contaminants from other than natural causes that may settle and have a deleterious effect on the aquatic biota or that will significantly alter the physical or chemical properties of the water or the bottom sediments.

ii. Nuisance Conditions – Plant nutrients or other substances stimulating algal growth from other than natural causes shall not be present in concentrations that produce objectionable algal densities or nuisance aquatic vegetation, or that result in a dominance of nuisance species instream, or that cause nuisance conditions in any other fashion. Phosphorous and nitrogen concentrations shall not reach levels, which result in man-induced eutrophication problems.

iii. Salinity/Mineral Quality – (TDS, chlorides, and sulfates) existing mineral quality shall not be altered by municipal, industrial, or instream activities, or other water discharges so as to interfere with the designated or attainable uses for a water body. An increase of more than 1/3 over naturally occurring levels shall not be permitted. Numeric criteria for chlorides at 230 mg/L, for sulfates at 250 mg/L, and for TDS at 500 mg/L shall not be exceeded.

WQR 10.1, 10.2, 10.3, 12.0b, 13.0, 14.0

RIO GRANDE BASIN – THE MAIN STEM OF THE RIO GRANDE FROM THE HEADWATERS OF ELEPHANT BUTTE RESERVOIR UPSTREAM TO ALAMEDA BRIDGE (CORRALES BRIDGE), THE JEMEZ RIVER FROM THE JEMEZ PUEBLO BOUNDARY UPSTREAM TO THE RIO GUADALUPE, AND INTERMITTENT FLOW BELOW THE PERENNIAL REACHES OF THE RIO PUERCO AND JEMEZ RIVER WHICH ENTERS THE MAIN STEM OF THE RIO GRANDE

New Mexico Standards (20.6.4.105):

A. Designated Uses: irrigation, limited warmwater fishery, livestock watering, wildlife habitat, and secondary contact.

B. Standards:

(1) In any single sample: pH shall be within the range of 6.6 to 9.0, and temperature shall not exceed 32.2°C (90°F). The use-specific numeric standards set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) The monthly geometric mean of fecal coliform bacteria shall not exceed 1,000/100 mL; no single sample shall exceed 2,000/100 mL (see Subsection B of 20.6.4.13 NMAC)

(3) At mean monthly flows above 100 cubic feet per second (cfs), the mean monthly average concentration for: TDS shall not exceed 1,500 mg/L, sulfate shall not exceed 500 mg/L, and chloride shall not exceed 250 mg/L

(4) Narrative standards are those set forth in section 20.6.4.12 of the State of New Mexico Standards for Interstate and Intrastate Surface Waters. These include, but are not limited to:

i. Bottom Deposits – Surface waters of the State shall be free of water contaminants from other than natural causes that will settle and damage or impair the normal growth, function, or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.

ii. Plant Nutrients – Plant nutrients from other than natural causes shall not be present in concentrations, which will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the state.

iii. Turbidity – Turbidity attributable to other than natural causes shall not reduce light transmission to the point that the normal growth, function, or reproduction of aquatic life is impaired or that will cause substantial visible contrast with the natural appearance of the water.

WQR 11.1

RIO GRANDE BASIN – COCHITI RESERVOIR

New Mexico Standards (20.6.4.112):

A. Designated Uses: livestock watering, wildlife habitat, coldwater fishery, warmwater fishery, and primary contact.

B. Standards:

(1) In any single sample: pH shall be within the range of 6.6 to 9.0, temperature shall not exceed 25°C (77°F), and turbidity shall not exceed 25 NTU. The use-specific numeric standards set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL (see Subsection B of 20.6.4.13 NMAC)

(3) Narrative standards are those set forth in section 20.6.4.12 of the State of New Mexico Standards for Interstate and Intrastate Surface Waters. These include, but are not limited to:

i. Bottom Deposits – Surface waters of the State shall be free of water contaminants from other than natural causes that will settle and damage or impair the normal growth, function, or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.

ii. Plant Nutrients – Plant nutrients from other than natural causes shall not be present in concentrations, which will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the State.

iii. W hen changes in dissolved oxygen, temperature, dissolved solids, sediment or turbidity in a water of the state is attributable to natural causes or the reasonable operation of irrigation and flood control facilities that are not subject to federal or state water pollution control permitting, numerical standards for temperature, dissolved solids content, dissolved oxygen, sediment or turbidity adopted under the Water Quality Act do not apply. The foregoing provision does not include major reconstruction of storage dams or diversion dams except for emergency actions necessary to protect health and safety of the public, or discharges from municipal separate storm sewers.

WQR 11.2, 11.3

RIO GRANDE BASIN – THE MAIN STEM OF THE RIO GRANDE FROM ANGOSTURA DIVERSION WORKS UPSTREAM TO COCHITI DAM.

New Mexico Standards (20.6.4.110):

A. Designated Uses:irrigation, livestock watering, wildlife habitat, secondary contact, coldwater fishery, and warmwater fishery.

B. Standards:

(1) In any single sample: pH shall be within the range of 6.6 to 8.8, and temperature shall not exceed 25°C (77°F). The use-specific numeric standards set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) The monthly geometric mean of fecal coliform bacteria shall not exceed 200/100 mL; no single sample shall exceed 400/100 mL (see Subsection B of 20.6.4.13 NMAC)

(3) Narrative standards are those set forth in section 20.6.4.12 of the State of New Mexico Standards for Interstate and Intrastate Surface Waters. These include, but are not limited to:

i. Bottom Deposits – Surface waters of the State shall be free of water contaminants from other than natural causes that will settle and damage or impair the normal growth, function, or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.

ii. Plant Nutrients – Plant nutrients from other than natural causes shall not be present in concentrations, which will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the State.

iii. Turbidity – Turbidity attributable to other than natural causes shall not reduce light transmission to the point that the normal growth, function, or reproduction of aquatic life is impaired or that will cause substantial visible contrast with the natural appearance of the water.

WQR 12.0a

RIO GRANDE AT BERNALILLO TO SOUTH BOUNDARY OF SANDIA PUEBLO

Sandia Pueblo Standards:

A. Designated Uses:primary contact ceremonial, primary contact recreational, secondary contact recreational, agricultural, industrial

B. Standards:

- **(1)** Temperature = 32.2^o C, DO = 5mg/L, pH = 6.0-9.0, As = 17.5ng/L, fecal coliform = 100/100 mL, turbidity = 25 NTU
- **(2)** Narrative standards include, but are not limited to:
  - i. Stream Bottom Deposits – Surface waters shall be free from water contaminants from other than natural causes that may settle and have a deleterious effect on the aquatic biota or that will significantly alter the physical or chemical properties of the water or the bottom sediments.
  - ii. Salinity/Mineral Quality – (TDS, chlorides, and sulfates) existing mineral quality shall not be altered by municipal, industrial, or instream activities, or other water discharges so as to interfere with the designated or attainable uses for a water body. An increase of more than 1/3 over naturally-occurring levels shall not be permitted. Numeric criteria for chlorides at 230 mg/L, for sulfates at 250 mg/L, and for TDS at 500 mg/L shall not be exceeded.
  - iii. Nuisance Conditions – Plant nutrients or other substances stimulating algal growth from other than natural causes shall not be present in concentrations that produce objectionable algal densities or nuisance aquatic vegetation, or that result in a dominance of nuisance species instream, or that cause nuisance conditions in any other fashion. Phosphorous and nitrogen concentrations shall not reach levels, which result in man-induced eutrophication problems. Total P shall not exceed 100 ug/L instream or 50 ug/L in lakes in reservoirs except waters highly laden with natural silts or color which reduce the penetration of light needed for photosynthesis, or in other waters where it can be demonstrated that algal production will not interfere with or adversely affect designated and other attainable uses.

WQR 12.0c

SEGMENT OF THE RIO GRANDE THAT PASSES THROUGH PUEBLO OF ISLETA

Isleta Pueblo Standards:

A. Designated Uses: primary contact ceremonial, primary contact recreational, secondary contact recreational, agricultural, industrial

B. Standards:

- **(1)** Temperature = 32.2^o C, DO = 5mg/L, pH = 6.0-9.0, As = 17.5ng/L, fecal coliform = 100/100 mL, turbidity = 25 NTU
- **(2)** Narrative standards include, but are not limited to:
  - i. Stream Bottom Deposits – Surface waters shall be free from water contaminants from other than natural causes that may settle and have a deleterious effect on the

aquatic biota or that will significantly alter the physical or chemical properties of the water or the bottom sediments.

ii. Salinity/Mineral Quality – (TDS, chlorides, and sulfates) existing mineral quality shall not be altered by municipal, industrial, or instream activities, or other water discharges so as to interfere with the designated or attainable uses for a water body. An increase of more than 1/3 over naturally-occurring levels shall not be permitted. Numeric criteria for chlorides at 230 mg/L, for sulfates at 250 mg/L, and for TDS at 500 mg/L shall not be exceeded.

iii. Nuisance Conditions – Plant nutrients or other substances stimulating algal growth from other than natural causes shall not be present in concentrations that produce objectionable algal densities or nuisance aquatic vegetation, or that result in a dominance of nuisance species instream, or that cause nuisance conditions in any other fashion. Phosphorous and nitrogen concentrations shall not reach levels, which result in man-induced eutrophication problems. Total P shall not exceed 100 ug/L instream or 50 ug/L in lakes in reservoirs except waters highly laden with natural silts or color which reduce the penetration of light needed for photosynthesis, or in other waters where it can be demonstrated that algal production will not interfere with or adversely affect designated and other attainable uses.

WQR 15.1

RIO GRANDE BASIN – ELEPHANT BUTTE RESERVOIR

New Mexico Standards (20.6.4.104):

A. Designated Uses: irrigation storage, livestock watering, wildlife habitat, primary contact, and warmwater fishery.

B. Standards:

(1) At any sampling site: pH shall be within the range of 6.6 to 9.0, and temperature shall not exceed 32.2°C (90°F), and turbidity shall not exceed 50 NTU. The use-specific numeric standards set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL (see Subsection B of 20.6.4.13 NMAC).

(3) Narrative standards are those set forth in section 20.6.4.12 of the State of New Mexico Standards for Interstate and Intrastate Surface Waters. These include, but are not limited to:

i. Bottom Deposits – Surface waters of the State shall be free of water contaminants from other than natural causes that will settle and damage or impair the normal growth, function, or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.

ii. Plant Nutrients – Plant nutrients from other than natural causes shall not be present in concentrations, which will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the State.

iii. When changes in dissolved oxygen, temperature, dissolved solids, sediment or turbidity in a water of the state is attributable to natural causes or the reasonable operation of irrigation and flood control facilities that are not subject to federal or state water pollution control permitting, numerical standards for temperature, dissolved solids content, dissolved oxygen, sediment or turbidity adopted under the Water Quality Act do not apply. The foregoing provision does not include major reconstruction of storage dams or diversion dams except for emergency actions necessary to protect health and safety of the public, or discharges from municipal separate storm sewers.

WQR 15.2

RIO GRANDE BASIN – THE MAIN STEM OF THE RIO GRANDE FROM THE HEADWATERS OF CABALLO LAKE UPSTREAM TO ELEPHANT BUTTE DAM AND PERENNIAL REACHES OF TRIBUTARIES TO THE RIO GRANDE IN SIERRA AND SOCORRO COUNTIES. (FLOW IN THIS REACH OF THE RIO GRANDE MAIN STEM IS DEPENDENT UPON RELEASE FROM ELEPHANT BUTTE DAM.)

New Mexico Standards (20.6.4.103):

A. Designated Uses: fish culture, irrigation, livestock watering, wildlife habitat, marginal coldwater fishery, secondary contact, and warmwater fishery.

B. Standards:

- **(1)** At any sampling site: pH shall be within the range of 6.6 to 9.0, and temperature shall not exceed 25°C (77°F). The use-specific numeric standards set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.
- **(2)** The monthly geometric mean of fecal coliform bacteria shall not exceed 1,000/100 mL; no single sample shall exceed 2,000/100 mL (see Subsection B of 20.6.4.13 NMAC).
- **(3)** Narrative standards are those set forth in section 20.6.4.12 of the State of New Mexico Standards for Interstate and Intrastate Surface Waters. These include, but are not limited to:
  - i. Bottom Deposits – Surface waters of the State shall be free of water contaminants from other than natural causes that will settle and damage or impair the normal growth, function, or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.
  - ii. Plant Nutrients – Plant nutrients from other than natural causes shall not be present in concentrations, which will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the State.
  - iii. Turbidity – Turbidity attributable to other than natural causes shall not reduce light transmission to the point that the normal growth, function, or reproduction of aquatic life is impaired or that will cause substantial visible contrast with the natural appearance of the water.

WQR 16.1

RIO GRANDE BASIN – THE MAIN STEM OF THE RIO GRANDE FROM ONE MILE BELOW PERCHA DAM UPSTREAM TO THE HEADWATERS OF CABALLO RESERVOIR INCLUDING CABALLO RESERVOIR. (SUSTAINED FLOW IN THE RIO GRANDE BELOW CABALLO RESERVOIR IS DEPENDENT ON RELEASE FROM CABALLO RESERVOIR DURING IRRIGATION SEASON; AT OTHER TIMES OF THE YEAR, THERE MAY BE LITTLE OR NO FLOW.)

New Mexico Standards (20.6.4.102):

A. Designated Uses: irrigation, livestock watering, wildlife habitat, warmwater fishery, and primary contact.

B. Standards:

- **(1)** At any sampling site: pH shall be within the range of 6.6 to 9.0, and temperature shall not exceed 32.2°C (90°F), and turbidity shall not exceed 50 NTU. The use-specific numeric standards set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL (see Subsection B of 20.6.4.13 NMAC).

(3) Narrative standards are those set forth in section 20.6.4.12 of the State of New Mexico Standards for Interstate and Intrastate Surface Waters. These include, but are not limited to:

i. Bottom Deposits – Surface waters of the State shall be free of water contaminants from other than natural causes that will settle and damage or impair the normal growth, function, or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.

ii. Plant Nutrients – Plant nutrients from other than natural causes shall not be present in concentrations, which will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the State.

iv. W hen changes in dissolved oxygen, temperature, dissolved solids, sediment or turbidity in a water of the state is attributable to natural causes or the reasonable operation of irrigation and flood control facilities that are not subject to federal or state water pollution control permitting, numerical standards for temperature, dissolved solids content, dissolved oxygen, sediment or turbidity adopted under the Water Quality Act do not apply. The foregoing provision does not include major reconstruction of storage dams or diversion dams except for emergency actions necessary to protect health and safety of the public, or discharges from municipal separate storm sewers.

WQR 16.2

RIO GRANDE BASIN – THE MAIN STEM OF THE RIO GRANDE FROM THE INTERNATIONAL BOUNDARY AND WATER COMMISSION (IBWC) SAMPLING STATION ABOVE AMERICAN DAM UPSTREAM TO ONE MILE BELOW PERCHA DAM. (SUSTAINED FLOW IN THE RIO GRANDE BELOW CABALLO RESERVOIR IS DEPENDENT ON RELEASE FROM CABALLO RESERVOIR DURING THE IRRIGATION SEASON; AT OTHER TIMES OF THE YEAR, THERE MAY BE LITTLE OR NO FLOW).

New Mexico Standards (20.6.4.101):

A. Designated Uses: irrigation, limited warmwater fishery, livestock watering, wildlife habitat, and secondary contact

B. Standards:

(1) At any sampling site: pH shall be within the range of 6.6 to 9.0, and temperature shall not exceed 34°C (93.2°F). The use-specific numeric standards set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) The monthly geometric mean of fecal coliform bacteria shall not exceed 1,000/100 mL; no single sample shall exceed 2,000/100 mL (see Subsection B of 20.6.4.13 NMAC).

(3) At mean monthly flows above 350 cfs, the monthly average concentration for: TDS shall not exceed 2,000 mg/L, sulfate shall not exceed 500 mg/L, and chlorides shall not exceed 400 mg/L.

(4) Narrative standards are those set forth in section 20.6.4.12 of the State of New Mexico Standards for Interstate and Intrastate Surface Waters. These include, but are not limited to:

i. Bottom Deposits – Surface waters of the State shall be free of water contaminants from other than natural causes that will settle and damage or impair the normal growth, function, or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.

ii. Plant Nutrients – Plant nutrients from other than natural causes shall not be present in concentrations, which will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the State.

iii. Turbidity – Turbidity attributable to other than natural causes shall not reduce light transmission to the point that the normal growth, function, or reproduction of aquatic life is impaired or that will cause substantial visible contrast with the natural appearance of the water.

WQR 17.1, 17.2

RIO GRANDE ABOVE AND BELOW INTERNATIONAL DAM

Texas Water Quality Standards (Segments 2314 and 2308):

A. Designated Uses: contact recreation, public water supply

B. Standards:

(1) Temperature = 33.3^o C (WQR 17.1) and 33.9 ^{o} C (WQR 17.2), DO = 5mg/L, TDS = 1800 mg/L (WQR 17.1) and 1400 mg/L (WQR 17.2), pH = 6.5-9.0, As = 360 ug/L, Hg (fish tissue) = 0.0122 ug/L, fecal coliform = 126/200 mL.

(2) Narrative standards include, but are not limited to:

i. Surface water shall be essentially free of floating debris and suspended solids that are conducive to producing adverse responses in aquatic organisms or putrescible sludge deposits or sediment layers which adversely affect benthic biota or any lawful uses.

ii. Surface waters shall be essentially free of settleable solids conducive to changes in flow characteristics of stream channels or the untimely filling of surface water in the state. This provision does not prohibit dredge and fill activities, which are permitted in accordance with the Federal Clean Water Act.

iii. Nutrients from permitted discharges or other controllable sources shall not cause excessive growth of aquatic vegetation that impairs an existing, attainable, or designated use. Site-specific nutrient criteria, nutrient permit limitations, and/or separate rules to control nutrients in individual watersheds will be established where appropriate after notice and opportunity for public participation and proper hearing.

1.3 Water Quality Resource Team Objectives

Principal issues addressed by the Water Quality Resource Team included qualitative and quantitative measures that would best preserve water quality within the Rio Grande Basin. The team's objectives were to:

- Identify existing State and Tribal water quality standards and jurisdictional issues in the study area
- Document water quality in lentic and lotic systems
- Document historic and current river and reservoir water quality
- Correlate water quality data with historic reservoir operations
- Define historic seasonal changes in water quality on the Rio Grande (1975-2001)
- Estimate changes in water quality projected to occur under EIS alternatives to current water operations in the Rio Grande Basin
- Define cumulative effects on water quality from EIS alternatives
- Compare estimated water quality effects under EIS alternatives to applicable State and Tribal water quality standards

After review of all applicable standards, the WQRT developed a set of water quality resource indicators for both reservoirs and river reaches. Indicators were developed by preliminarily assessing the availability of water quality data in the project area and by identifying specific water quality constituents that were most likely to be affected by reservoir operations. Generally, constituents with numeric standards were selected. However, additional constituents were included if it was determined that they posed a specific human health threat, were uniquely influenced by reservoir operations, or were subject to antidegradation policies. The water quality constituents selected were those with adequate data available for analysis, most affected by reservoir operations, the best indicators of water quality, and of most interest to the Rio Grande watershed:

- Water Temperature
- Dissolved Oxygen
- Suspended Sediment/Turbidity
- Salinity/Specific Conductivity
- Total Dissolved Solids
- pH
- Arsenic
- Mercury
- Nutrients
- Fecal Coliform

2.0 WATER QUALITY CONDITIONS IN LOTIC AND LENTIC SYSTEMS

Water quantity and quality are more critical in arid to semi-arid environments than perhaps anywhere else due to the scarcity of water (Brooks et al. 1997). Generally, water quality in water bodies, whether lotic (moving, as in rivers and streams) or lentic (standing, as in lakes and reservoirs) refers to the temperature of the water and the amount of dissolved gases and solids, suspended solids, pathogenic organisms, and hydrogen ions (H+) within the water (Dingman 1994). Water is considered to be polluted when the concentration of a constituent may adversely affect or alter the aquatic ecosystem or violate any specified water quality standard. In a riverine environment, water quality is negatively affected by inputs to and losses from the stream, whether anthropogenic or natural, that degrade the environment and add pollutants. Water quality in reservoirs is subject to natural degradation from eutrophication and anthropogenic impacts that could speed eutrophication.

The impacts of reservoir operations on surface water quality, both within the reservoirs and in the streams they modify, are of increasing concern to water managers, planners, scientists, and landowners faced with balancing the storage and delivery of water for agricultural, urban, industrial, and environmental use. Water impoundments can create a unique ecosystem with altered water quality conditions both in the reservoir and downstream. Drainage basin characteristics influence both riverine and reservoir water quality, as inflows to a reservoir play a significant role in determining reservoir water quality dynamics. Dissimilar water quality characteristics are often found at the point of inflow, but mixing nearly always occurs in a reservoir, creating widely varying water quality conditions at the reservoir outflow. Reservoir operations, including flood control and irrigation storage, can also impact water quality by altering constituent composition and downstream transport of materials that enter the reservoirs from upstream river reaches.

2.1 Water Quality Constituents

The U.S. Geological Survey (USGS) has conducted the majority of the water quality research in the Rio Grande watershed. Additional water quality data have been collected by numerous other entities including the States of Colorado, New Mexico, and Texas, the U.S. Environmental Protection Agency (EPA), the International Boundary and Water Commission (IBWC), and various other local, state, and federal entities. The following discussion describes the most significant water quality constituents in the lotic and lentic systems of the Rio Grande Basin and assesses their impacts.

2.1.1 Surface Water Temperature

Riverine water temperature varies seasonally and daily and from location to location, based on factors that include short-term and long-term climate, altitude, extent of streamside vegetation, and relative importance of groundwater inputs (Allan 1995). Water temperature fluctuations closely follow seasonal trends in air temperature. However, spring-fed and headwater streams with constant groundwater inflow have stable water temperatures throughout the year, even with large changes in air temperature. Water temperature in temperate rivers ranges annually between 0°C and 25°C. Desert streams can reach temperatures as high as 40°C, while headwater and spring-fed streams at high elevations rarely exceed 15°C (Allan 1995). Since water follows gravity from higher to lower elevations, temperatures are generally lowest in headwater reaches and steadily increase to warmer temperatures in lower reaches.

Daily variation in lotic water temperature depends on stream/river size, weather conditions, and the extent of riparian vegetation. Because of the volume of water involved, large rivers have little daily variation in water temperature. Small headwater and spring-fed streams also show little daily variation due to shading and constant groundwater input. Waterways with significant amounts of riparian vegetation will be shaded and thus maintain relatively low water temperatures. However, unshaded streams of intermediate size may have daily temperature fluxes of up to 10°C (Allan 1995).

Water temperature plays a crucial role in the presence or absence and distribution of aquatic flora and fauna in riverine environments. For many faunal species, large water temperature fluxes and/or a higher mean temperature can inhibit particular stages in the life cycle and thus decrease numbers. These changes in mean temperature are especially detrimental to fish populations (Horne and Goldman 1994). Existing species may be replaced, which may ultimately alter the quality of local water.

Water impoundment behind dams can alter water temperature trends even in large rivers, especially downstream of the dam. Reservoirs created behind large dams produce stratified thermal regimes similar to those in lakes, in which the surface layer will be warmer than the river water before impoundment and the deep water will be much colder. Since the temperature of the river below the dam depends on the temperature of release water, surface releases (of reservoir water that is close to the surface) will cause higher than average river water temperatures, and bottom releases will cause much colder average water temperatures (Allan 1995). Such thermal regime changes can alter the ecosystem below the dam.

Not only biological processes but chemical processes as well depend on temperature. Temperature regime changes within a reservoir are the result of the combined effects of natural processes and reservoir operations, especially inflows and outflows (Dasic and Djordjevic 2002). Direct absorption of solar energy is the primary mechanism responsible for heating the water in a reservoir (Wetzel 1983). Sediments, either settled or suspended, also absorb much of the incoming solar radiation. The sediments have the ability to absorb heat during warmer periods and transmit that heat to the water during winter, and may play a much more vital role in thermal absorption in small reservoirs than in large ones (Likens and Johnson 1969).

Stratification is a seasonal phenomenon that is driven by summer temperatures substantially raising the temperature of the upper water layers. In typical thermal stratification of a reservoir, the impounded water becomes separated into three strata: epilimnion, metalimnion, and hypolimnion (Figure M-1). As water temperature increases, its density decreases (Figure M-2), and surface waters warmed by insolation will thus remain at the surface of the water body, forming the epilimnion, while the denser, cooler water settles at the bottom, forming the hypolimnion. The intermediate layer is the metalimnion, and the layer of rapid temperature change separating the two layers (epilimnion and hypolimnion) is called the thermo cline (Smith 1990).

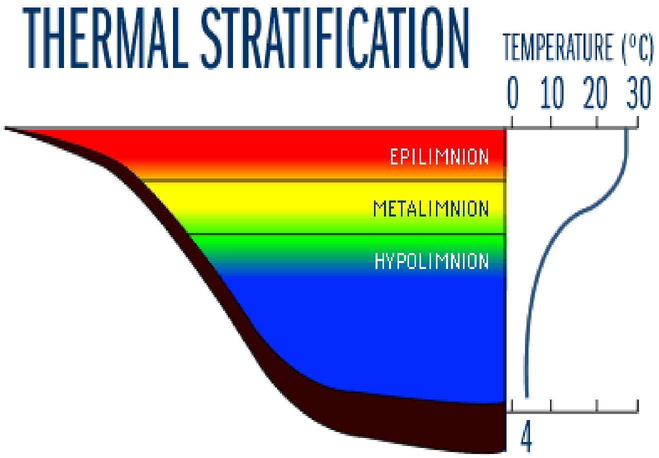

Figure M-1. Typical stratification of a reservoir (courtesy http://www.shorelandmanagement.org).

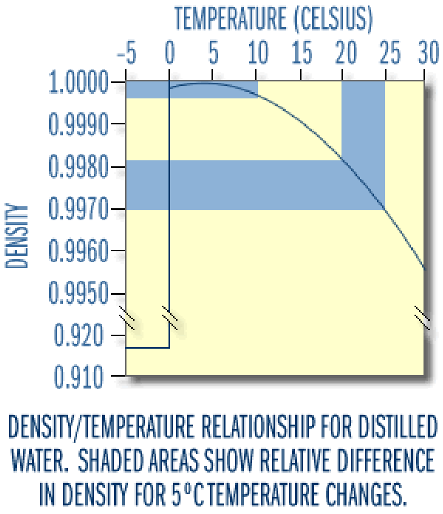

Figure M-2. Density and temperature relationships in bodies of water (courtesy http://www.shorelandmanagement.org).

In the fall, with lowered heat input into the reservoir system, the epilimnion waters cool, become denser, and sink. Stratification is lost as the reservoir water mixes and turns over, restoring a more uniform temperature throughout the water body. In the spring, with the influx of snowmelt, stratification will break down further, and any slight wind will initiate turnover within the system, mixing nutrients and oxygen. Spring or fall turnover may last for weeks in larger reservoirs, affecting water quality not only in terms of temperature but also through changes in nutrient distribution, turbidity, and dissolved oxygen (Wetzel 1983).

2.1.2 Dissolved Oxygen and Carbon Dioxide

Dissolved oxygen (DO) and carbon dioxide (CO_2) occur in significant amounts in streams and rivers. Exchange between the water surface and the atmosphere, coupled with stream turbulence and organism respiration, supplies the water with these dissolved gases. The amount of dissolved oxygen and carbon dioxide depends on pressure, surface water temperatures, altitude, and the synergistic effects of other constituents (Smith 1990). Cold, fast-flowing waters have higher dissolved oxygen levels, while warm, slow-moving waters have lower oxygen content. In flowing water, mixing takes place along the air-water interface, where oxygen-rich water is constantly being replaced by water that contains less oxygen through mixing and turbulence. Stagnant water goes through less internal mixing, except during seasonal turnover, and dissolved oxygen values are lower throughout the column of water. Since the water is not moving, dissolved oxygen values decrease due to respiration, decomposition of organic matter, and increases in water temperature. Runoff from agricultural lands and sewage effluent can also contribute to lower dissolved oxygen levels and promote eutrophication.

Small, turbulent streams with limited pollution maintain stable dissolved oxygen and carbon dioxide levels via diffusion, but high biological activity in larger rivers alters oxygen and carbon dioxide levels through photosynthetic and organic respiration processes. In eutropic (nutrient rich) systems with high levels of photosynthetic organisms, oxygen is elevated and carbon dioxide is reduced during the day, when photosynthesis takes place; during the night the reverse occurs as respiration dominates (Allan 1995). Organic pollution can greatly increase microbial levels, with a concomitant increase in the demand for oxygen, causing low oxygen levels, and increased respiration, elevating carbon dioxide levels. Concentrations of dissolved oxygen vary due to synergistic reactions with other constituents. For example, dissolved oxygen solubility increases with decreasing salinity levels.

Dissolved oxygen is essential to the life cycle of aerobic aquatic organisms and can be a critical environmental variable, as biotas of lotic waters constantly depend on its availability (Hynes 1970). Prolonged exposure to low dissolved oxygen levels will increase an organism's susceptibility to environmental stresses (Dingman 1994). In reservoirs, problems occur seasonally or synergistically when dissolved oxygen reacts to changes in other constituent levels. Low dissolved oxygen concentrations can lead to releases in reservoirs—and thus into downstream waters—of such gases as ammonia (H_3N), methane (CH_4), and hydrogen sulfide (H_2S) (Dasic and Djordjevic 2002), which may create a toxic environment for aquatic organisms. Levels of dissolved oxygen are governed by anthropogenic inputs and by natural processes, both atmospheric and photosynthetic. Dissolved oxygen will also vary by season and with changes in stratification within the reservoir (Tchobanoglous and Schroeder 1987).

Dissolved oxygen levels in reservoirs are commonly highest in water near the surface, where mixing and photosynthetic processes occur. However, at the beginning of the summer, the colder hypolimnion will contain more dissolved oxygen than the surface layers. As the summer progresses, microbial decomposition increases, resulting in an oxygen-deficient hypolimnion and higher dissolved oxygen levels near the reservoir surface. This process may be accelerated by an influx of nutrients into the reservoir; creating a eutrophic state and further depleting dissolved oxygen in the hypolimnion (Smith 1990).

Two other considerations related to dissolved oxygen are biological oxygen demand (BOD) and chemical oxygen demand (COD). BOD reflects the concentration of organic wastes that have the ability to consume dissolved oxygen, or the amount of oxygen consumed during the breakdown of organic matter within the water. COD is a measure of pollutant loading using oxidation agents (chemical oxidation). COD is not necessarily a good indicator of oxygen demands within waters (Brooks et al. 1997).

2.1.3 Total Dissolved Solids and Salinity

The measure of total dissolved solids (TDS) represents the sum of all major dissolved ion concentrations in freshwater. TDS in most streams and rivers is dominated by the weathering of sedimentary rock, but varies widely due to many natural and anthropogenic sources. Common ions include calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), silica, bicarbonate (CHO_3^--), chloride (Cl^--), and sulfate (O_4S^{-2}-$_2$). Pollution from domestic sewage, fertilizers, road salt, and mining activities can substantially increase sodium, chloride, and sulfate while slightly increasing other ions. Specific conductivity, a measure directly related to TDS, is a measure of electrical conductance of ions, and an approximate predictor of total dissolved ions. When surface flows decrease, the concentration of TDS may increase, increasing conductivity. *Salinity* is often used interchangeably with TDS. Generally, surface water TDS concentrations in fluvial systems increase with the length of time the water has been in the hydrologic system (Levings et al. 1998). Processes such as evapotranspiration, transpiration, and dissolution of minerals increase the concentration of dissolved solids.

Sodium chloride (NaCl), salt, concentrations are expected to be high in arid to semi-arid areas where evaporation exceeds precipitation. As water evaporates from existing water bodies, salt concentrations increase. In addition, because precipitation itself contains traces of NaCl, evaporation after a precipitation event deposits salt in soils. These salts may be transported in irrigation return flow or in overland flow during rainstorm runoff (Pefetti and Terrel 1989). Additional salts are added to waterways from the weathering of minerals in soils (Walton and Ohlmacher 1998; Wilson 1999).

Generally, processes that influence TDS, conductance, and salinity are the same in lentic and lotic systems. In reservoirs, waters with high TDS levels (saline water) will sink to the hypolimnion because of their density and will not mix well with other reservoir water, commonly leading to decreased dissolved oxygen levels in the hypolimnion (Gower 1980).

2.1.4 pH

Reservoir pH values that are excessively high or low can have adverse affects on water quality (Dingman 1994). The acidic or basic condition of a water body is determined by measuring the concentration of hydrogen ions (Allan 1995) and is commonly expressed as pH. A pH of 7 is the neutral condition. A pH greater than 7 is alkaline and occurs when carbonate (CO_3^{-2}-$_2$) and bicarbonate are present. A pH less than 7 is acidic. Variation in pH is due to natural and anthropogenic inputs and synergistic affects. As flow decreases, pH can increase with increased concentrations of total dissolved solids. An increase in pH commonly signals increased ammonia (H_3N) levels (U.S. EPA 1987). At pH values above 9, ammonia can be very toxic to organisms in high enough concentrations (NRC 1979). Carbon dioxide can also affect pH values (Brooks et al. 1997). Acidification of aquatic systems inhibits microbial activity, reducing decomposition and nutrient cycling. This can lead to a decrease in the number of plants and/or invertebrates within the system, eventually affecting higher organisms as well. As pH decreases, the increased acidity of the water may also release toxic metals that would otherwise be bonded to sediment. The heavy metal ions may dissolve into solution and become available for uptake by various organisms (Connell and Miller 1984), becoming lethal if uptake is too great.

Water temperature can also affect pH. Rainwater is naturally acidic, but soil neutralizes the acidity over time. However, industrial emissions have increased the acidity of rain, thus lowering the pH in many freshwaters. Values below 5 or above 9 are harmful to most aquatic organisms. The acidity or alkalinity of water can also act synergistically with other organic material and carbon (C) to affect water quality. Organic material can lower pH, while the calcium bicarbonate ($C_2H_2CaO_6$) content of freshwater normally determines the pH balance (Allan 1995).

2.1.5 Turbidity and Suspended Sediments

Turbidity is a measure of the degree to which light can travel through inorganic particles and suspended organics that are scattered in the water column. Turbidity can greatly affect water quality and induce changes that may alter the composition of an aquatic community (Wilber 1983). For example, as a result of higher turbidity caused by a large volume of suspended sediment, sunlight may not be able to penetrate deep into the water, altering primary production in the uppermost layers (McCabe and Sandretto 1985). Reduced light penetration can suppress photosynthetic activity of algae, macrophytes, and phytoplankton, decreasing the availability of photosynthetic organisms as food sources for invertebrates, which may in turn lead to an overall decline in fish and other aquatic populations.

Suspended sediment refers to sand- to clay-sized particles suspended in the water column and is generally a function of stream or river size, surrounding land use conditions, geology, and erodibility of the drainage basin, and discharge and water velocities. An increase in streamflow velocity related to natural occurrences such as snowmelt or ephemeral storm inflows, or anthropogenic changes in reservoir operations and wastewater inflows, can result in higher concentrations of suspended sediment within a system (Moore and Anderholm 2002). eservoirs may greatly alter sediment concentration and turbidity within a river system. Dams and reservoirs can serve as settling basins, greatly reducing turbidity (Crossman 1998) and affecting transport and deposition of sediments, nutrients, and chemicals downstream. Suspended sediments within a reservoir usually consist of the smallest particles, predominantly silts and clays (Dunne and Leopold 1978). However, dams also interrupt the downstream transport of larger particles, including sands and gravels. Nutrients and Heavy Metals

The term *nutrient* refers to any inorganic material that is necessary for life. Nutrients in lotic water occur as ions or dissolved gases and are affected by chemical, physical, and biological processes. An example of a physical process is the adsorption of nutrients to inorganic surfaces such as suspended sediments; a chemical process is oxidation; and two major biological processes that affect nutrients are assimilation and excretion (Allan 1995). Nutrients in streams and rivers vary widely based on location and season, geology, rainfall, stream size, surrounding landscape patterns and land use, and human influence. Nutrients in small streams are determined primarily by local geology and organic material in the watershed. Nutrient loads are often modified by human-related activities such as industrial emissions, sewage effluent, agricultural and urban runoff, and water impoundments. Common nutrients in lotic waters include: carbon, nitrogen (N), phosphorus (P), silica, and many ions and trace elements.

Heavy metal loading is directly correlated with the amount of sediment being transported into the waterway. Agricultural erosion and runoff from construction sites and unvegetated areas are primary sources of both sediments and metals (Morton 1986; McCabe and Sandretto 1985). Other primary sources of heavy metal and nutrient loading include runoff from mining operations (past and present), road construction, and wildfire burn areas.

Nitrogen and phosphorus are primary nutrients found in both lentic and lotic waters. The levels and transport of these nutrients vary naturally based on season, climate, discharge, floods, atmospheric diffusion, geology of the watershed, and biological input. For example, streams that are fed by snowmelt have large fluctuations in discharge, and therefore a large flux in nutrient concentrations and transport. Anthropogenic sources include sewage effluent, agricultural and urban runoff, and industrial emissions alter nitrogen and phosphorus levels. For example, nitrogen often increases in agricultural and urban areas, while phosphorus generally increases in sewage effluent areas. Combinations of factors in a watershed determine fluctuations of these nutrients. Nitrate (HNO_3) levels are controlled by pH, biological nitrogen fixation, and denitrification, freezing and thawing cycles, runoff from fires, erosion, and presence or absence of vegetation. itrogen can occur in reservoirs in various forms. Most nitrogen input into a reservoir is considered to come from surrounding land, not the atmosphere. Anthropogenic nitrogen is directly related to agricultural fertilizers, sewage and industrial waste runoff, and atmospheric pollution. On a localized scale, grazing can influence nitrogen transformation rates and microbial populations (Wetzel 1983). Nitrogen, unlike oxygen and carbon dioxide, is not very soluble in water. Maximum concentrations are often found during the winter when solubility increases with colder temperatures (Wetzel 1983). High concentrations of nitrates can stimulate algal growth (Brooks et al. 1997). If phosphorus is present, small amounts of nitrates can stimulate large algal blooms. Cycling of nitrogen may be adversely impacted by retention time, reservoir elevation fluctuations, and releases from the reservoir.

The impact of phosphorus on lentic and lotic systems has been studied intensively. Lakes and reservoirs act as phosphorus sinks, playing a major role in biological metabolism and reservoir productivity. Phosphorus may enter the reservoir through flowing water (inflow) and leave the system through flowing water (outflow). Phosphorus can also reach reservoirs through precipitation events, although concentrations in precipitation are extremely low, usually lower than the amount of nitrogen. The amount of phosphorus entering reservoirs is directly related to the amount of phosphorus in soils and geology, topography (slope), and vegetation. The addition of phosphorus can substantially change the quality of water, and can induce eutrophication. Eutrophication results in an increase in algae and biomass (Brooks et al. 1997) when high levels of phosphorus and nitrogen are input into the reservoir system. However, very low phosphorus levels also limit biological productivity.

Reservoir sediments generally contain high levels of phosphorus. When sediments are disturbed, phosphorus is released and mixes throughout the water body. Phosphorus stored in the uppermost layers of the reservoir bottom sediments is subject to bioturbation and chemical transformations. The reducing conditions often present in a hypolimnion during winter months may induce the release of phosphorus from sediments, which may stimulate algal blooms (Dickson et al. 1982). If all the phosphorus within a reservoir system is used, plant growth will cease, no matter how much nitrogen is available (Dunne and Leopold 1978).

Algal production is directly correlated with the levels of both nitrogen and phosphorus in a reservoir. If the nitrogen-to-phosphorus ratio (N:P) is above 10:1, the potential for an algal bloom increases drastically (Schindler 1978; Jaworski 1981). Although algal blooms generally do not pose direct health effects, certain species of algae can produce exotoxins that may be harmful to various aquatic life. An abundance of algae will shade deeper waters and prevent normal photosynthetic activity from occurring (Dennison et al. 1993), a decline in essential habitat that can negatively affect the entire ecosystem.

2.1.6 Fecal Coliform

Fecal matter can be deposited directly in reservoirs and waterways via sewage discharges and wildlife, or indirectly from groundwater, sediments, and stormwater overland or channel flow (Weiskel *et al.* 1996; Wakelin et al. 2003).

2.1.7 Arsenic

Arsenic (As) in surface water can be the result of natural processes or anthropogenic activities. Arsenic is found in water as organic and inorganic compounds. Inorganic compounds include arsenite (As_4O_6) and arsenate (AsH_3O_4); arsenite is ten times more toxic than arsenate. Anthropogenic sources include pesticides, industrial compounds, and fertilizers.

2.1.8 Mercury

Mercury (Hg) is a highly toxic element that is found both naturally and athropogenically in the environment. Elevated levels of mercury can make fish toxic to eat. At high concentrations, mercury can cause birth defects and nerve tissue degeneration (Johnson 1995). The toxic effects of mercury depend on its chemical form. Methylmercury (CH_3Hg^++), the most toxic form, can be traced to metal processing, medical wastes, and atmospheric deposition from activities such as the burning of coal (USGS 2000). Once mercury is in the atmosphere, it is disseminated and can circulate for a number of years before being deposited into waterways. Natural sources of mercury include volcanic eruptions, geologic deposits, and thermal hot springs. Most water, soil, and rock contain small amounts of mercury (USGS 2000).

2.1.9 Sulfur and Hydrogen Sulfide

Sources of sulfur (S) in reservoirs include contributions from local geology, fertilizers, and industrial emissions. Sulfates ($O_4S^{-2}{-}_2$) may exist in precipitation. Sulfur can have a negative impact on water quality when large amounts of hydrogen sulfide (H_2S) are added to the system by industrial or biogenic sources. Hydrogen sulfide is very soluble in water and generally is found to be present in waters with pH values below 7. Nriagu and Hem (1978) found that an increase in sulfides tends to lower pH.

3.0 SELECTED CONSTITUENTS OF WATER QUALITY IN THE RIO GRANDE BASIN HISTORIC TRENDS AND CURRENT CONDITIONS

The WQRT compiled a database of water quality records for the Rio Grande, its tributaries, and its mainstem reservoirs. Sources for the data were the U.S. Geological Survey (USGS), U.S. Environmental Protection Agency (EPA), International Boundary and Water Commission (IBWC), and New Mexico Environment Department (NMED). •Tables WQ 2-6 summarize the compiled data.) USGS data were the most extensive, but were not always available. A few gages had large data gaps, and some had no data at all. Once datasets were compiled, analysis methods and modeling techniques were formulated (see Chapter 4). Water quality constituents, USGS gages, and specific reaches, or stream sections, were identified to analyze historic trends and current conditions in the Rio Grande Basin. To better understand these trends and conditions, the WQRT developed a series of objectives:

- Develop statistical correlations between constituents
- Identify data availability
- Identify data gaps
- Collect existing information and reports on water quality in the Rio Grande
- Collect existing information and reports on water quality in reservoirs of the Rio Grande
- Develop long-term and seasonal trend data to better understand how constituents change geographically and temporally

3.1 Data Availability and Analysis

3.1.1 Data Availability

A comprehensive, basin-wide analysis of water quality data from 1975 to the present identified gaps in the data and characterized conditions within the Basin over time. Reaches of the Rio Grande with adequate data were selected to determine the relationships between surface water quality and reservoir operations. At each selected location, correlation statistics were used to derive relationships between water quality constituents and operations.

Table M-2 shows the number of total records by constituent for the mainstem Rio Grande and its tributaries. The purpose of the table is to identify both data gaps and data abundance. *Reach Type* indicates whether the data are related to gages along the Rio Grande mainstem (e.g., Otowi, San Acacia) or on tributaries. The table reflects data collected at USGS gages from 1975 to 2001, with the potential of approximately 9,860 days worth of data for each constituent. Constituents analyzed include turbidity; dissolved oxygen (DO); dissolved oxygen percent saturation (% DOsat); pH; salinity; specific conductivity (SC); air temperature; water temperature; total dissolved solids (TDS); fecal coliform; total coliform; arsenic (As); hydrogen sulfide (H_2S); mercury (Hg); and suspended sediments (Susp Sed). The table shows that there are large gaps in the data for salinity and hydrogen sulfide, two constituents that are of primary concern in the Southern Section of the Rio Grande Basin.

Table M-2. Number of Total Records (Data Availability) by Constituent for the Mainstem and Tributaries of the Rio Grande

Reach Type	Turbidity	DO	%DOsat	pH	Salinity	SC	Air Temp	Water Temp
Mainstem	1137	2431	1150	4584	1	4563	1997	6455
Tributary	34	175	141	584	0	951	173	1203

Reach Type	TDS	Fecal Coliform	Total Coliform	As	H_2S	Hg	Susp Sed
Mainstem	4688	983	170	623	0	427	4272
Tributary	955	41	10	57	0	11	731

Table M-3 indicates the number of total records by constituent for the five primary river gage sections: Northern, Chama, Central, San Acacia, and Southern. The Northern Section consists of gages along headwater tributaries of the Rio Grande and those to the north of Otowi along the mainstem Rio Grande. The Chama Section includes four gages: Above Abiquiu, Below Abiquiu, and Chamita on the Rio Chama, and Otowi on the Rio Grande. The Central Section consists of all the gages from below Cochiti Dam to Bernardo. The San Acacia Section includes the gages at San Acacia and San Marcial. The Southern Section includes principal gages from below Elephant Butte Dam to Fort Quitman, Texas.

At least some data gaps were identified for each water quality constituent and river section. There were data gaps in all river sections for hydrogen sulfide, and in all but one for salinity. Data were also often lacking for mercury and total fecal coliform loads. Overall, the Northern Section had the fewest available data, while the San Acacia Section had the most. Data were adequate for water temperature, total dissolved solids, specific conductivity, and dissolved oxygen in each river section.

Tables M-4a through M-4e identify the number of total records by constituent for the primary gages in each river section, by subreach and gage number (Station ID). The data shown inthesein these tables were used to analyze current conditions along the Rio Grande and contributing waterways and to model input data.

Table M-3. Number of Total Records (Data Availability) by Constituent for the Five Primary River Sections

Section	Turbidity	DO	%DOsat	pH	Salinity	SC	Air Temp	Water Temp
Northern	207	513	221	672	0	659	143	726
Chama	183	472	278	1237	1	1601	364	1499
Central	83	320	235	774	0	859	508	1661
San Acacia	318	540	264	1390	0	1614	684	2606
Southern	380	761	293	1095	0	781	471	1166

Section	TDS	Fecal Coliform	Total Coliform	As	H2S	Hg	Susp Sed
Northern	680	181	56	122	0	96	394
Chama	1608	208	49	140	0	77	1191
Central	860	135	0	106	0	52	1213
San Acacia	1615	257	28	126	0	103	1953
Southern	880	243	47	186	0	110	252

Table M-4a. Number of Total Records by Constituent for the Primary Northern Section Gages

Station Name	Reach ID	Station ID	Section	Reach Type	Turbidity	DO	%DOsat	pH	Salinity
Rio Grande near Lobatos, CO	01.4	8251500	Northern	Main	110	371	125	474	0
Rio Grande below Taos Junction	03.3	8276500	Northern	Main	97	142	96	198	0

Station Name	SC	Air Temp	Water Temp	TDS	Fecal Coliform	Total Coliform	As	H2S	Hg
Rio Grande near Lobatos, CO	465	39	524	478	111	56	80	0	63
Rio Grande below Taos Junction	194	104	202	202	70	0	42	0	33

Table M-4b. Number of Total Records by Constituent for the Primary Chama Section Gages

Station Name	Reach ID	Station ID	Section	Reach Type	Turbidity	DO	%DOsat	pH	Salinity	SC
Rio Chama above Abiquiu	06.2	8286500	Chama	Trib	9	12	0	5	0	107
Rio Chama below Abiquiu	07.2	8287000	Chama	Trib	0	6	0	7	0	107
Rio Chama near Chamita	07.3	8290000	Chama	Trib	25	130	115	319	0	452
Rio Grande at Otowi	09.0	8313000	Chama	Main	149	324	163	906	1	935

Station Name	Air Temp	Water Temp	TDS	Fecal Coliform	Total Coliform	As	H_2S	Hg	Susp Sed
Rio Chama above Abiquiu	5	214	107	0	5	0	0	0	209
Rio Chama below Abiquiu	0	194	107	0	0	0	0	0	191
Rio Chama near Chamita	92	499	456	41	5	34	0	11	312
Rio Grande at Otowi	267	592	938	167	39	106	0	66	479

Table M-4c. Number of Total Records by Constituent for the Primary Central Section Gages

Station Name	Reach ID	Station ID	Section	Reach Type	Turbidity	DO	%DOsat	pH	Salinity	SC
Rio Grande at San Felipe	10.2	8319000	Central	Main	51	176	93	181	0	182
Jemez River below Jemez Canyon Dam	11.3	8329000	Central	Trib	0	27	26	253	0	285
Rio Grande at Albuquerque	12.0.b	8330000	Central	Main	18	45	44	77	0	95
Rio Grande near Bernardo	13.0	8332010	Central	Main	14	72	72	263	0	297

Station Name	Air Temp	Water Temp	TDS	Fecal Coliform	Total Coliform	As	H2S	Hg	Susp Sed
Rio Grande at San Felipe	188	219	183	132	0	51	0	30	184
Jemez River below Jemez Canyon Dam	76	296	285	0	0	23	0	0	19
Rio Grande at Albuquerque	98	598	95	3	0	13	0	9	553
Rio Grande near Bernardo	146	548	297	0	0	19	0	13	457

Table M-4d. Number of Total Records by Constituent for the Primary San Acacia Section Gages

Station Name	Reach ID	Station ID	Section	Reach Type	Turbidity	DO	%DOsat	pH	Salinity	SC
Conveyance Channel at San Acacia	14.0	8354800	San Acacia	Main	33	76	10	88	0	92
Floodway at San Acacia	14.0	8354900	San Acacia	Main	20	92	78	103	0	112
Conveyance Channel at San Marcial	14.0	8358300	San Acacia	Main	61	182	85	675	0	745
Floodway at San Marcial	14.0	8358400	San Acacia	Main	204	190	91	524	0	665

Station Name	Air Temp	Water Temp	TDS	Fecal Coliform	Total Coliform	As	H2S	Hg	Susp Sed
Conveyance Channel at San Acacia	136	451	92	67	0	6	0	6	358
Floodway at San Acacia	100	588	113	60	0	32	0	24	589
Conveyance Channel at San Marcial	160	614	745	44	26	36	0	33	415
Floodway at San Marcial	288	953	665	86	2	52	0	40	591

Table M-4e. Number of Total Records by Constituent for the Primary Southern Section Gages

Station Name	Reach ID	Station ID	Section	Reach Type	Turbidity	DO	%DOsat	pH	Salinity	SC
Rio Grande below Elephant Butte	15.2	8361000	Southern	Main	123	72	1	132	0	244
Rio Grande at Leasburg	16.2	8363500	Southern	Main	11	92	69	97	0	99
Rio Grande at El Paso, TX	17.1	8364000	Southern	Main	150	461	191	705	0	438
Rio Grande at Fort Quitman, TX	17.2	8370500	Southern	Main	96	136	32	161	0	0

Station Name	Air Temp	Water Temp	TDS	Fecal Coliform	Total Coliform	As	H2S	Hg	Susp Sed
Rio Grande below Elephant Butte	98	306	244	29	0	14	0	14	29
Rio Grande at Leasburg	51	100	99	0	0	14	0	13	34
Rio Grande at El Paso, TX	223	620	440	114	7	96	0	60	189
Rio Grande at Fort Quitman, TX	99	140	97	100	40	62	0	23	0

3.1.2 Data Analysis

Data analysis focused on identification of statistical correlations among constituents and physical or chemical variables and the evaluation of seasonal and long-term trends in water quality. Data analysis was not completed for every gage and reach in the Rio Grande Basin. Instead, identified data gaps allowed the WQRT to focus on gages and reaches that had adequate data sets.

3.2 Gage Selection and Rationale

Data collected after 1975 and subjected to standard Quality Control practices were selected by the WQRT for further analysis. Two reservoirs (Abiquiu and Cochiti) and 18 USGS gaging stations (Table M-5) were selected for detailed analysis based on the availability of data at those sites and their respective locations within the basin. Generally, water temperature, dissolved oxygen, TDS/conductivity, and pH datasets were adequate for analysis. Arsenic, turbidity/suspended sediment, mercury, and hydrogen sulfide datasets were very limited, with small quantities of data present at a few gages. The remaining reservoirs and gage locations in the Basin were not selected for further evaluation because of the lack of suitable water quality data.

Table M-5. The Eighteen Gage Stations Used in the Water Quality Models

Reach ID	Station Name	Station ID	Section
01.4	Rio Grande near Lobatos, CO	8251500	Northern
03.3	Rio Grande below Taos Junction Bridge	8276500	Northern
06.2	Rio Chama above Abiquiu	8286500	Chama
07.2	Rio Chama below Abiquiu	8287000	Chama
07.3	Rio Chama near Chamita	8290000	Chama
09.0	Rio Grande at Otowi	8313000	Chama
10.2	Rio Grande at San Felipe	8319000	Central
11.3	Jemez River below Jemez Canyon Dam	8329000	Central
12.0.b	Rio Grande at Albuquerque	8330000	Central
13.0	Floodway near Bernardo	8332010	Central
14.0	Conveyance at San Acacia	8354800	San Acacia
14.0	Floodway at San Acacia	8354900	San Acacia
14.0	Conveyance at San Marcial	8358300	San Acacia
14.0	Floodway at San Marcial	8358400	San Acacia
15.2	Rio Grande below Elephant Butte Dam	8361000	Southern
16.2	Rio Grande at Leasburg	8363500	Southern
17.1	Rio Grande at El Paso, TX	8364000	Southern
17.2	Rio Grande at Fort Quitman, TX	8370500	Southern

3.3 Current Surface Water Quality Conditions and Correlations

Water quality relationships in the Rio Grande Basin are complex. Correlations among constituents vary from gage to gage due to the numerous natural and anthropogenic influences affecting the watershed. To assess relationships of discharge and air temperature with other water quality constituents, pairwise, pairwise Pearson’s Correlations were run for every constituent (Table M-6). Constituent data were log-transformed as appropriate to determine best correlations. Modeled after Healy (1997), for any relationship, if the Pearson’s correlation coefficient is greater than or equal to 0.7, or less than or equal to –0.7, it is a strong correlation. If the correlation is between 0.3 and 0.7, or between –0.3 and –0.7 then it is a moderate correlation. If the correlation coefficient is between –0.3 and 0.3, then there is no correlation. Constituents with wide data ranges were natural log transformed to normalize the data. According to Ramsey and Schafer, if the ratio between the largest and smallest measurements is greater than ten or if the data is not normally distributed (skewed right or left), log transformation is a good choice. Log transformed data can be analyzed the same as non-transformed, normally distributed data. Correlation analysis facilitated development of descriptive empirical models for analysis of potential alternative impacts and to identify potential multicollinearity in the modeled data. Only significant correlations and correlations important in the models are described below. For minor correlations, refer to Table M-6.

Table M-6. Correlations among All Evaluated Water Quality Constituents

	Discharge	Log Discharge	Turbidity	log Turbidity	Dissolved Oxygen	pH	Hg concentration	Conductivity	log Conductivity	Air Temperature	Water Temperature	TDS	log TDS	Suspended Sediments	log Suspended Sediments	Fecal Coliform Counts	log Fecal Coliform Counts
Discharge	1.000																
log Discharge	0.994	1.000															
Turbidity	0.114	0.945	1.000														
log Turbidity	0.308	0.725	0.975	1.000													
Dissolved Oxygen	-0.173	-0.297	-0.442	0.927	1.000												
PH	-0.141	-0.079	-0.027	0.107	0.939	1.000											
Hg concentration	0.064	0.057	0.023	-0.074	-0.792	0.904	1.000										
Conductivity	-0.593	-0.087	-0.222	0.114	0.032	0.006	0.937	1.000									
log Conductivity	-0.647	-0.101	-0.221	0.139	0.067	-0.018	0.900	0.997	1.000								
Air Temperature	0.183	0.209	0.315	-0.589	-0.025	-0.003	-0.131	-0.162	0.930	1.000							
Water Temperature	0.123	0.193	0.343	-0.603	-0.019	-0.009	-0.122	-0.151	0.799	0.990	1.000						
TDS	-0.603	-0.115	-0.236	0.134	0.015	0.017	0.919	0.943	-0.061	-0.109	0.941	1.000					
log TDS	-0.652	-0.143	-0.241	0.165	0.051	-0.008	0.885	0.975	-0.101	-0.157	0.900	0.997	1.000				
Suspended Sediments	0.054	0.558	0.554	-0.168	-0.164	0.140	0.129	0.079	0.086	0.164	0.151	0.085	0.931	1.000			
log Suspended Sediments	0.293	0.497	0.645	-0.251	-0.209	0.136	-0.038	-0.106	0.102	0.264	-0.011	-0.100	0.652	0.971	1.000		
Fecal Coliform Counts	0.093	0.282	0.183	-0.212	-0.243	0.209	0.136	0.108	-0.047	0.128	0.116	0.063	0.401	0.367	0.942	1.000	
log Fecal Coliform Counts	0.209	0.302	0.336	-0.310	-0.319	0.220	0.044	0.012	0.020	0.215	0.037	-0.017	0.335	0.455	0.667	0.984	1.000

Water quality constituents in the Rio Grande change along the length of the river as well as seasonally and temporally. Both non-point and point source pollution affects water quality in the Rio Grande Basin. Non-point sources of runoff from the watershed include urban areas, forested areas, and agricultural areas. Point sources are directly input into a water body from a source such as a feedlot, wastewater treatment plant, or factory. Wastewater affluent inflows from larger municipalities such as Albuquerque, Rio Rancho, El Paso, and Las Cruces are significant, sometimes contributing large amounts of discharged material to the Rio Grande (Moore and Anderholm 2002).

3.3.1 Air Temperature

Air temperature data acquired from NOAA Weather Services were used as a correlate for seasonal constituents such as water temperature and dissolved oxygen. The correlation analysis shows a strong correlation between air temperature and water temperature at most gages, and a strong to moderate correlation between air temperature and temperature and DO. At some gages, air temperature also showed some moderate correlations with pH with pH, conductivity, fecal coliform, and total arsenic.

3.3.2 Water Temperature

Water temperature increases from north to south throughout the system (Figure M-3). The highest recorded temperatures occur during summer months and were measured at gages downstream of the Albuquerque gage. The lowest surface water temperatures were recorded in the Rio Grande headwaters and along the Rio Chama during winter months. However, all stations exhibited lower temperatures in winter months and increasing temperatures through the spring and summer. Higher air temperatures during summer months likely cause these changes.

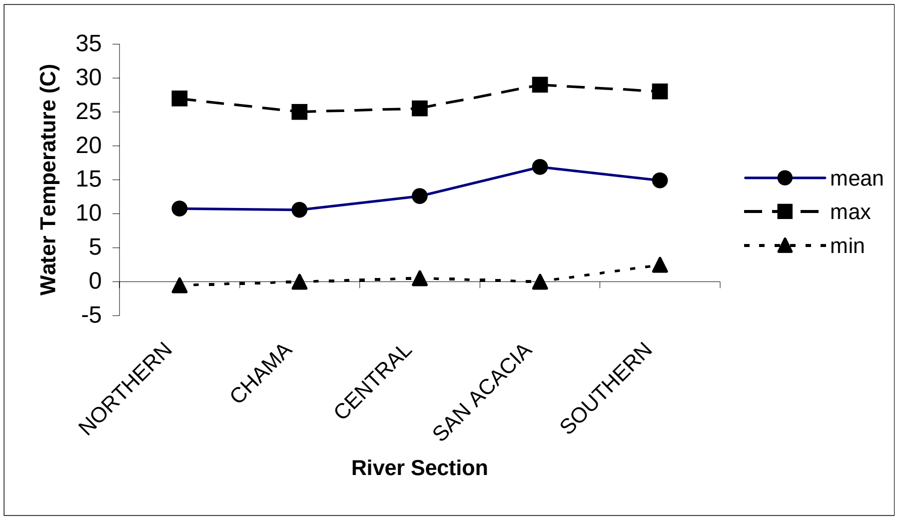

Figure M-3. Mean, minimum, and maximum water temperatures per river section.

Reservoirs may impact the water temperature in the Rio Grande. However, datasets from directly below the major Rio Grande dams are limited. Bottom-release dams discharge cold water from the hypolimnion into the stream surface water, thus causing stream water temperatures to be colder than normal. Small differences in maximum temperatures were observed below Elephant Butte Reservoir. Data from the gage below Elephant Butte indicated that maximum summer temperatures were approximately 8°C lower below the dam than in the reservoir inflow near San Marcial (28°C below Elephant Butte Dam versus 36°C at San Marcial). However, the average and minimum temperatures were not noticeably different below the dam. Available data showed no noticeable difference between water temperatures at inflows and outflows of Abiquiu and Cochiti dams... The gages above and below Abiquiu Dam had water temperature data only for limited periods and were not suitable for comparison purposes. Data from the gage below Cochiti Reservoir also were limited, and this gage also was not selected for the analysis.

Water temperature was generally lower with high discharges, usually in association with reservoir operations and/or runoff. High water temperature values were generally associated with low discharges and the high air temperatures that occur in summer months. Water temperature showed a strong to moderate negative correlation with DO at most gages. Some gages showed moderate correlations between water temperature and the natural log of discharge, concentration of suspended sediment, fecal coliform, and total arsenic.

3.3.3 Dissolved Oxygen

The concentration of dissolved oxygen in water is dependent on water temperature, salinity, and atmospheric pressure. Oxygen is incorporated into water, and dissolved oxygen levels are affected by three primary mechanisms: diffusion from surrounding air, oxygen production during photosynthesis, and aeration caused by natural and artificial turbulence processes. Dissolved oxygen is necessary for all forms of aquatic life in the Rio Grande Basin. Dissolved oxygen levels above 5.0 mg/L are optimal for the success of aquatic life forms. Values below 5.0 mg/L increase the stress on aquatic communities.

Available data were insufficient to establish baseline conditions for dissolved oxygen at the Rio Chama gages above and below Abiquiu Reservoir but were adequate for all other gages. The presence of dissolved oxygen varies greatly by season, with the lowest dissolved oxygen values being directly correlated with higher air and water temperatures. The lowest values were recorded during the warmest time of the year. The northernmost gages (those with lower water temperatures) had noticeably higher average levels of dissolved oxygen than gages in the southern reaches (higher water temperatures) (Figure M-4).

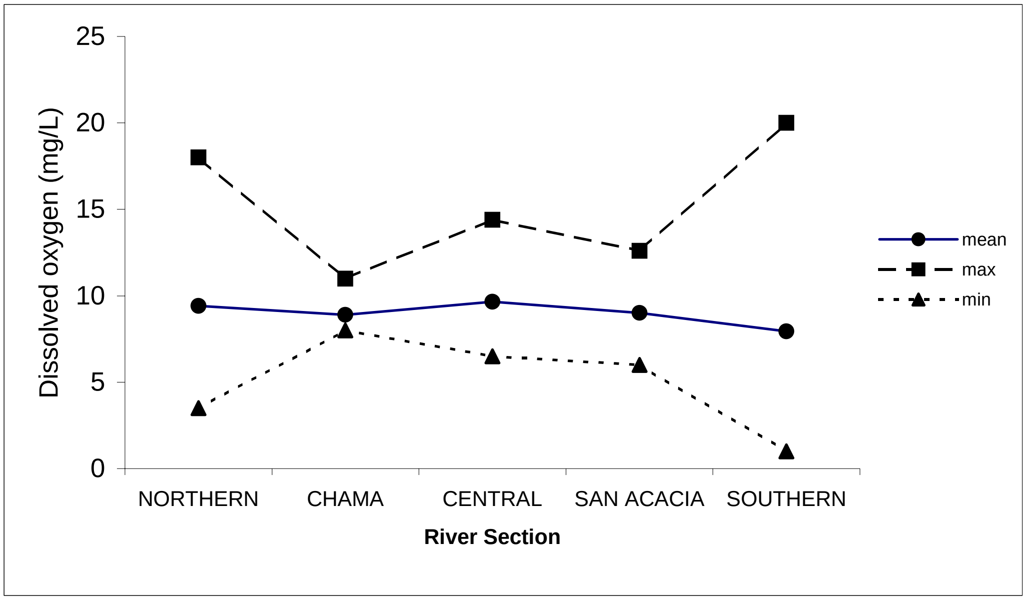

Figure M-4. Mean, minimum, and maximum dissolved oxygen values per river section.

Dissolved oxygen concentrations measured at the gage below Elephant Butte Dam were noticeably different from those observed at the other gage locations in the Rio Grande Basin. During winter months, the below Elephant Butte gage exhibited the highest average dissolved oxygen value in the Basin (11.71 mg/L), but had the lowest dissolved oxygen concentrations during summer and fall months. Average dissolved oxygen concentrations during summer months below Elephant Butte Reservoir were 3 mg/L less than those measured at the San Marcial gage near the reservoir inflow during the same time (3.9 mg/L below Elephant Butte versus 6.9 mg/L at San Marcial). No other gages had average dissolved oxygen concentrations below 7.2 mg/L during the same period.

Thermal stratification and oxygen limitations that have been observed in the Elephant Butte Reservoir hypolimnion are possible explanations for the substantially different dissolved oxygen readings. During the winter and at the beginning of the summer, the hypolimnion may contain more dissolved oxygen because colder water holds more oxygen than warmer water. During summer months, microorganisms break down organic materials in the hypolimnion, consuming dissolved oxygen. Continued microbial decomposition eventually results in an oxygen-deficient hypolimnion. If the lake is eutrophic, or nutrient rich, this process may be accelerated by increased microbial activity, and the dissolved oxygen in the lake could be depleted before the end of summer. This process and the release of the oxygen-depleted water may contribute to the low dissolved oxygen levels observed below Elephant Butte Dam. This same process may occur in Abiquiu Reservoir, where data collected by the U.S. Army Corps of Engineers indicate that a similar zone of oxygen-deprived water may occur during August and September at depths greater than 10 m. However, data were not available to assess whether water with low oxygen levels is discharged from the reservoir (U.S. Army Corps of Engineers 2001).

The dissolved oxygen content of the Rio Grande correlates negatively with water temperature (lower temperature = higher DO). DO was also strongly to moderately correlated with air temperature, indicating that DO is affected by season. There were moderate correlations between DO and the concentration of suspended sediments and fecal coliform loads. At some gages, there were moderate correlations between DO and TDS and turbidity. Many of these constituents may not be directly affected by DO, but may simply respond to the same environmental correlates in the river system.

3.3.4 Total Dissolved Solids/Conductivity

Total dissolved solids (TDS) are the sum of the organic and inorganic materials dissolved in the water, and can be used as an indicator of water quality. TDS is composed of organic matter, salts, minerals, and metals originating from both natural and anthropogenic sources. Anthropogenic sources include faster vapor-transpiration rates caused by impoundments, leaching of agricultural chemicals, and wastewater effluent. Natural sources include mineral dissolution, precipitation, and evapo-transpiration (Moore and Anderholm 2002).

Data from the gages above and below Abiquiu Dam were insufficient to establish baseline conditions for TDS. TDS were highest in the middle and lower reaches of the basin and lowest in the upper reaches (Figure M-5). Many of the northern gages, including the gages above Cochiti Dam in the Northern and Chama Sections and at San Felipe, Albuquerque, and Bernardo in the Central Section, had relatively low TDS (100-300 mg/L). At the Jemez River gage there was an influx of higher loads of total dissolved solids. However, the relatively low volume of water entering the mainstem Rio Grande at the Jemez River confluence did not noticeably increase TDS values downstream. Below the Albuquerque gage, TDS began to increase. There was a slight seasonal increase at Bernardo, then substantial increases at San Acacia and San Marcial, followed by a decrease as the river flowed through Elephant Butte Reservoir and Dam. The highest levels of TDS in the system were found downstream at the El Paso and Fort Quitman gages, where they were consistently high throughout each season. Fort Quitman TDS values were higher than the averages recorded at any other gage in the system. Throughout the system, the highest TDS values occurred during winter and summer/fall periods. Most of the gages in the system had their lowest average values during the period associated with snowmelt runoff.

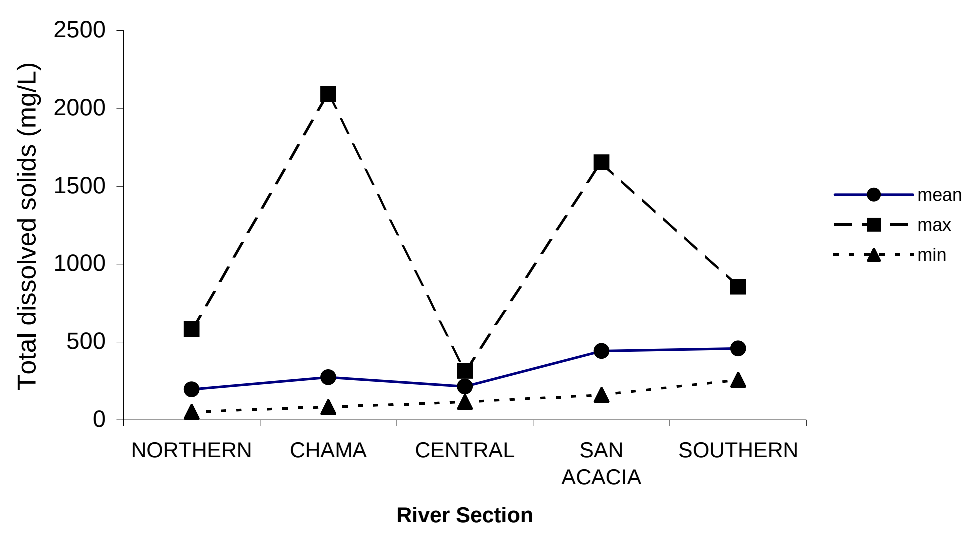

Figure M-5. Mean, minimum, and maximum total dissolved solids values per river section.

Conductivity is the measure of water's ionic content and hence its ability to conduct electricity. The higher the content of ionic material, the higher the conductivity of the water. Conductivity is directly related to water temperature. Specific conductivity can be a good measure of water salinity and total dissolved solids. Conductivity within the Rio Grande system varies with latitude and the inflow of major tributaries. In lower reaches of the Rio Grande system, adjacent land uses are likely causes of conductivity changes.

Total dissolved solids correlate strongly to moderately with discharge. The natural log values of both TDS and discharge generally had stronger correlations than the non-transformed values. TDS was also strongly correlated with conductivity at all gages. The strong correlation existed because TDS and conductivity measure basically the same parameter—dissolved solids in the water system. A few gages show moderate correlations between TDS, air temperature, and water temperature.

3.3.5 pH

Sufficient data existed to establish baseline conditions for pH at all selected locations except the gages above and below Abiquiu Reservoir. Average pH values remained relatively consistent between gages in the basin (Figure M-6). Average pH for all gages was 8.1 (minimum average = 8.0 at Conveyance Channel near San Acacia, maximum average = 8.3 at Leasburg).

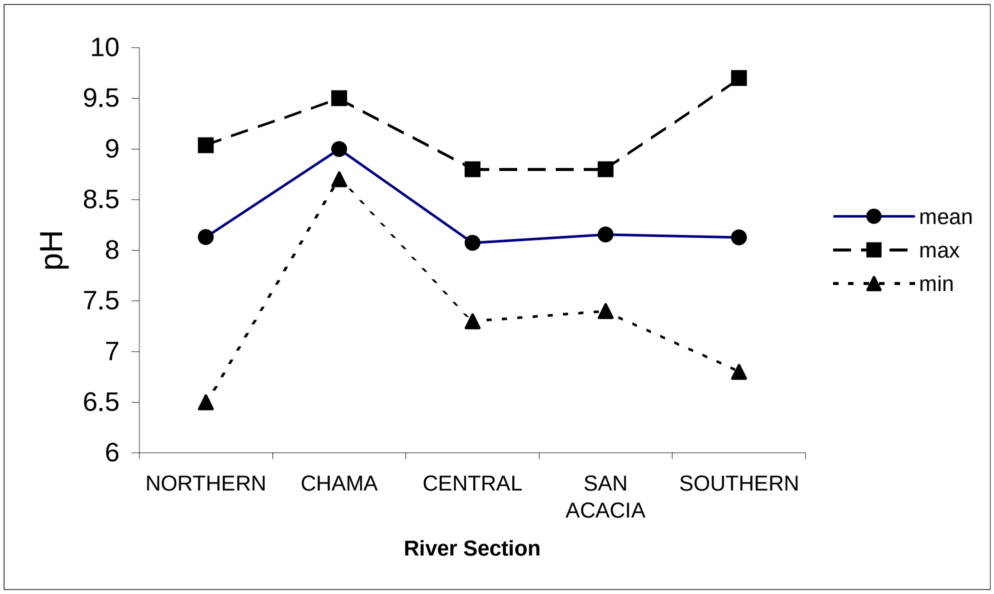

Figure M-6. Mean, minimum, and maximum pH values per river section.

Very few relationships were evident between pH and other water quality constituents. However, pH was strongly correlated with dissolved oxygen at the gage below Elephant Butte Dam (Pearson’s correlation coefficient = 0.73). When dissolved oxygen decreased at the Elephant Butte gage, a corresponding decrease in pH (the water became more acidic) was evident. Passell et al. (2004) found significant increases in pH at Albuquerque and downstream.

Correlations between pH and other constituents were weak. The pH values across all gages were between 7.0 and 9.0. Finding strong linear relationships with data in such a small range is difficult. However, at a few gages, the pH values had moderate correlations with discharge, concentration of suspended sediment, water temperature, TDS, and fecal coliform counts. The pH was back-transformed to the hydrogen ion concentration, but this did not improve the strength of any correlations or models.

3.3.6 Turbidity/Suspended Sediments

Water velocity largely determines the composition of the suspended load. Turbidity can greatly affect water quality and induce changes that may alter the composition of an aquatic community (Wilber 1983). For example, higher turbidity (caused by a large volume of suspended sediment) may result in reduced light infiltration. At each selected gage there is variation within the system because of a series of factors, one being reservoir operations. The reservoirs have the ability to filter a portion of the sediment behind the dam, releasing far less than the amount that flows into the reservoir.

Turbidity varies by season and latitude throughout the Rio Grande system. The lowest turbidity values were between the months of November and February, with values increasing as the year progressed. Values were highest during the warmer months, when runoff from storm events rapidly increased river discharge and increased the load of suspended sediments and turbid waters. Turbidity and suspended sediment loads also increased downstream. Values were lowest in the Northern and Rio Chama sections and were highest in the San Acacia section, where the river was heavily influenced by inflows from the Rio Puerco and Rio Salado as well as other large tributaries upstream in the Albuquerque area (Figure M-7).

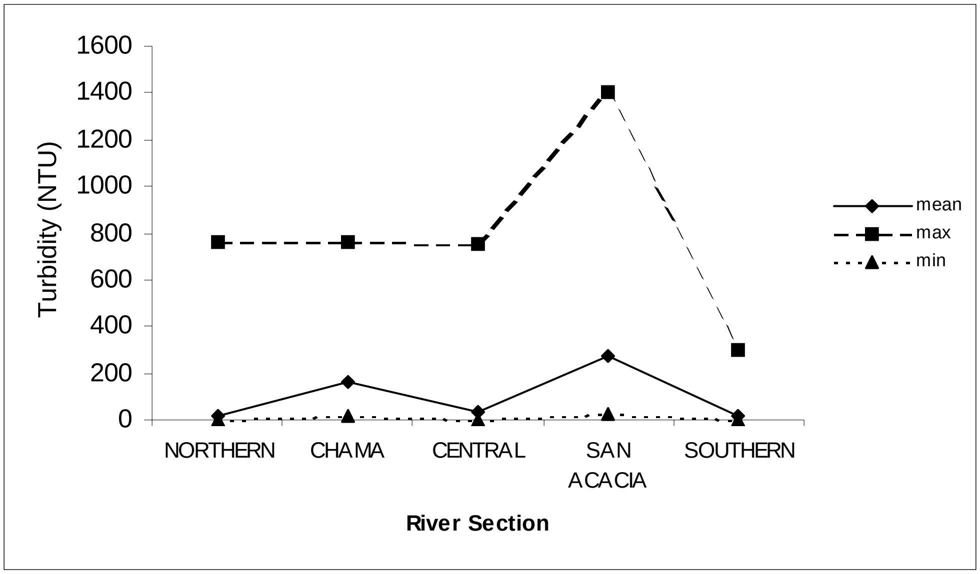

Figure M-7. Mean, minimum, and maximum turbidity values per river section. Units of measurement for turbidity in Nephelometric Turbidity Units (NTUs).

At the headwaters of the Rio Grande, suspended sediment decreased between gages, as groundwater and tributary inflows with low concentrations of suspended sediments dilute the Rio Grande and the landscape of the headwaters lacks erodable material. Suspended sediment concentrations increased downstream but were interrupted by reservoirs, where the particles settled out of the water column (Levings et al. 1998) (Figure M-8). The Rio Salado and Rio Puerco contribute large quantities of sediment to the Rio Grande, and gages below these tributaries had high suspended sediment concentrations.

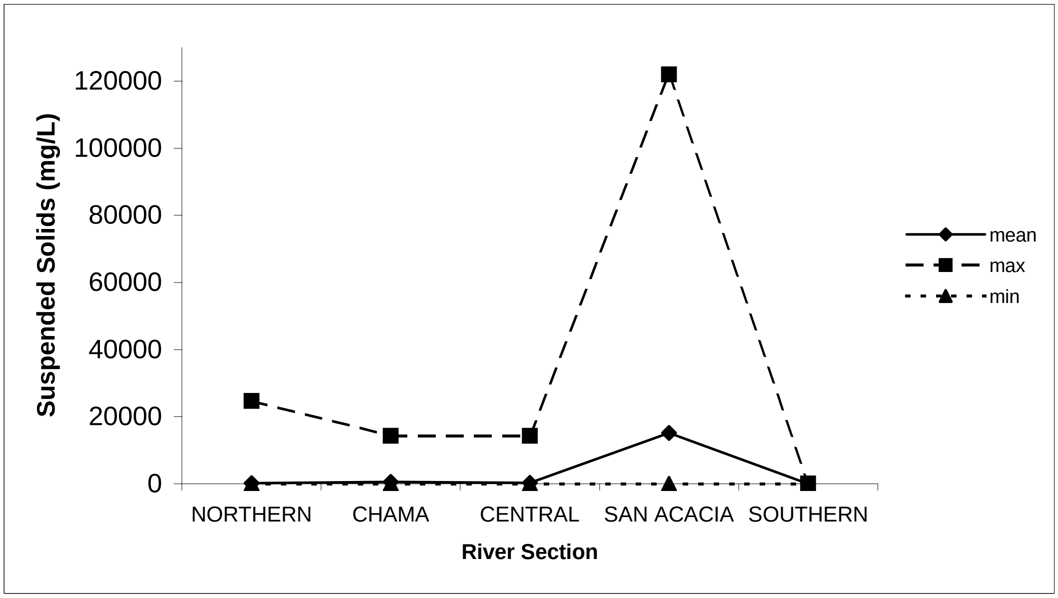

Figure M-8. Mean, minimum, and maximum suspended sediments values per river section.

Measurements of the amount of sediment being transported in the Rio Grande and its inflowing tributaries assisted in determining the amount of aggradation and degradation within the river. Areas of the San Marcial Reach have accumulated 25 feet of sediment over the last 100 years (Wilson 1999). Seasonal inflows from the Rio Puerco and Rio Salado, ephemeral tributaries that carry large sediment loads, contributed much of the sediment. The Rio Puerco, the largest contributing watershed within the Rio Grande Basin, contributes 45 percent of the sediment to the river but only 3 percent of the runoff (Hay 1972).

Turbidity correlates strongly to moderately with the concentration of suspended sediments and moderately correlated with dissolved oxygen, air temperature, water temperature, and fecal coliform counts. The natural log of the concentration of suspended sediments correlates strongly to moderately with the natural log of turbidity. The correlation between these two constituents is similar to that between TDS and conductivity. Turbidity may be used to model the concentration of suspended sediments or vice versa. The natural log of suspended sediments concentration was also moderately correlated with the natural log of fecal coliform counts.

3.3.7 Fecal Coliform

Fecal coliform is found in intestinal tracts of warm-blooded animals, and its presence is an indicator of pathogens in the waterway. Data for fecal coliform loads were limited in most of the Rio Grande Basin. In addition, there is a recent movement to use *E. coli* as an indicator of bacterial contamination rather than the broader class of fecal coliforms. Fecal coliform loads follow the same general pattern shown in turbidity/suspended sediments (Figure M-9). In general, loads of fecal coliform were highest following natural inflows from summer storm events. These events mobilize fecal material from upland sources and transport the contaminating bacteria to the Rio Grande, where water temperatures are suitable for fecal coliform activity. During winter and spring runoff events, low water temperatures may limit some fecal activity. Reservoirs act as sinks for fecal loads in the Rio Grande Basin, and lower mean values for fecal coliform counts occur downstream of Cochiti and Elephant Butte Reservoirs. Contamination from fecal coliform adds surplus organic matter to the system, and bacterial respiration lowers the amount of oxygen present. The lower oxygen levels may endanger aquatic life and can lead to fish kills.

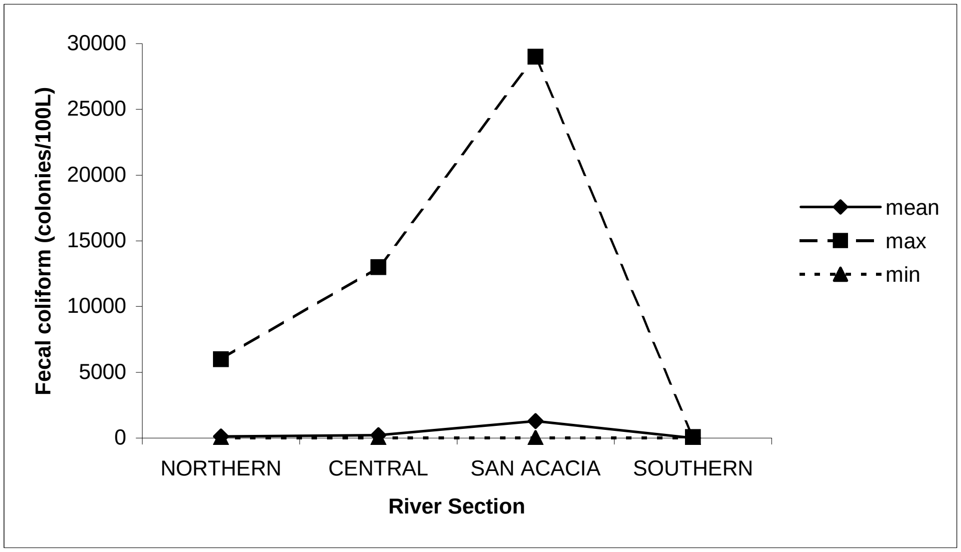

Figure M-9. Mean, minimum, and maximum fecal coliform values per river section.

Fecal coliform counts moderately correlated with turbidity, natural log of suspended sediments, and dissolved oxygen. Some gages had moderate correlations between fecal coliform, air temperature, and water temperature. High fecal coliform counts seem to occur with intermediate discharges. However, the correlation between fecal coliform and discharge was a challenge to model because high discharge dilutes fecal coliform counts. Several gages had little or no fecal coliform data, so modeling was further challenged.

3.3.8 Arsenic

Arsenic contamination usually occurs in groundwater rather than in surface water. However, arsenic can be found in surface water as a result of either natural or anthropogenic conditions. In the Rio Grande Basin, the geology of the Jemez Mountains and surrounding areas contributes natural arsenic loads to surface waters. Generally, arsenic is associated with volcanic rocks because these rocks are relatively high in arsenic, and because magmatic fluids also mobilize arsenic associated with silicic intrusions (Chapin and Dunbar 1994). Anthropogenic activities such as mining and farming affect arsenic levels as well. Arsenic data were very limited in the dataset used for analysis. However, the data available suggest that arsenic loads remain consistent throughout the year, with little variation. Arsenic levels at the Jemez River gage (see Table M-4c) were high throughout the year and may contribute to increased arsenic loads downstream of the confluence of the Jemez and the Rio Grande. Arsenic levels were lower above the Jemez–Rio Grande confluence than at the Jemez River gage, and were higher below the confluence. Overall, arsenic is lower in the northern reaches and higher in the southern reaches.

Dissolved arsenic in the northern Rio Grande Basin was low (2 ppb on average), but increased downstream to the confluence of the Jemez River. Arsenic values were 28-66 ppb on average near the confluence (Chapin and Dunbar 1994). Wilcox (1997) found that dissolved arsenic concentrations were 2 mg/L at the San Felipe Gage, 14-20 mg/L in the Jemez River, and 11-20 mg/L at the Rio Rancho and Bernalillo Wastewater Treatment Plant (WWTP), and 4 mg/L at Los Lunas. Most rivers in the contiguous United States contain less than 1 ppb of arsenic (Lettenmaier et al. 1991).

Arsenic can also be found in soils. According to Norman and Dilley (2002), irrigated soils in the Rio Grande Valley are arsenic "time bombs," where concentrations in the San Acacia Reach decrease during the winter when irrigation is not occurring.

3.3.9 Mercury

Insufficient data were available to establish conditions for mercury in the surface waters of the Rio Grande Basin.

3.3.10 Nutrients

The largest concentrations of nutrients in the Rio Grande were either associated with suspended sediments or detected downstream of urban areas. Nutrients adsorb quickly to suspended sediments; thus, high nutrient concentrations were also associated with high levels of suspended sediments (Levings et al. 1998). Elevated nutrient concentrations in urban areas were associated with wastewater treatment plants.

3.3.11 Nitrates

Nitrate (HNO_3) concentrations in the Rio Grande generally increased downstream. Headwater gages (e.g., Lobatos and Chama) had low nitrate concentrations (< 0.05 mg/L) because the area has little development and large surface water inflow. Sites downstream (e.g., Otowi) also had relatively low nitrate concentration (< 0.12 mg/L) due to dilution by groundwater and surface water (tributary) inflows. Two tributaries, the Conejos River and the Rio Chama, had low dissolved nitrate levels, and sites below their confluences with the Rio Grande had low nitrate concentrations due to dilution. Through agricultural land and the metropolitan area of Albuquerque, nitrate concentrations in the Rio Grande increased from 0.06 mg/L to 0.66 mg/L due to agricultural return flows and wastewater treatment plant effluent. Nitrate concentrations decreased downstream of Elephant Butte and Caballo Reservoirs due to settling and higher rates of nutrient uptake. Below Leasburg Dam and El Paso gages, nitrates increased again due to WWTP effluent.

Rio Grande nitrate concentrations vary seasonally, primarily because of snowmelt, which contains low levels of nitrates. On the other hand, the longer days and warmer temperatures associated with snowmelt in spring and summer increase nitrogen uptake.

3.3.12 Phosphorus

Total phosphorus concentrations also generally increased downstream due to groundwater and/or tributary inflow between sites, WWTP effluent, and agricultural return flows (via fertilizer application). Over half of the phosphorus measurements between 1992 and 1995 exceeded the recommended levels (Levings et al. 1998). Tributaries contribute large amounts of sediment to the Rio Grande, and phosphorus adsorbs to suspended sediments; thus, larger phosphorus concentrations are recorded below the confluences with tributaries. Phosphorus settles in Elephant Butte and Caballo Reservoirs, but concentrations were high again below Leasburg and El Paso due to WWTP effluent and agricultural runoff.

3.3.13 Pesticides

Pesticides enter the Rio Grande system via application to urban lawns and agricultural fields. Pesticides were detected at 94% of all sites sampled, but levels were below EPA drinking water standards (Levings et al. 1998). Please see Healy (1997) () for a more detailed analysis of pesticides in the upper Rio Grande Basin.

3.3.14 Salinity

High salinity levels in the Rio Grande inhibit agricultural and municipal use. Return flows, predominantly agricultural, greatly increase the level of salinity in the river. Although fluvial increases in salinity can be both natural and anthropogenic, the major causes of increases in the Rio Grande are from changes in land use, diversions from rivers, and irrigation return flows. Walton and Ohlmacher (1998) found that conductivity and chloride concentrations increased during the winter months and near El Paso when irrigation drains discharge more water to the river. Municipal use near El Paso increased salinity 200-300 mg/L as it transitions to treated wastewater (Turner 1998).

3.4 Current Reservoir Water Quality Conditions

Most reservoirs are operated according to policies dictated by intrastate and interstate laws, decrees, and legal agreements. A variety of natural and anthropogenic factors should be considered in evaluating water management scenarios. For example, prolonged storage, reduced or increased reservoir flushing/discharge rates, low reservoir turnover rates, and greater reservoir depths can produce stagnation of the hypolimnetic waters of some reservoirs. Stagnation generally leads to oxygen depletion (especially where nutrient or dissolved organic inputs to the reservoir are high) and elevated concentrations of many dissolved metals and other contaminants. Operating reservoirs to reduce retention times and maintain lower water depths in summer and autumn can reduce such problems.

Managing water quality related to reservoirs requires consideration of both reservoir operations and influences from the surrounding watershed. The water quality environment affected by the alternatives considered under this EIS includes not only the waters in the reservoirs and their downstream discharges, but also all water from the Rio Grande watershed draining into the reservoirs. The three large dams that affect the mainstem of the Rio Grande are Cochiti, Elephant Butte, and Caballo. The Rio Chama, a major tributary of the Rio Grande, is impacted by Heron, El Vado, and Abiquiu reservoirs. Natural flow regimes, which normally peak during spring snowmelt and monsoon season, have been altered and are now in fact controlled by reservoir operations and diversions. Reservoir operations may be planned to mitigate against any negative effects, creating an environment with similar seasonal flows.

Changes in reservoir operations may have both negative and positive impacts. Water quality can be affected by changes in reservoir water level, the length of time the water is in the reservoir, and the size of releases from the dam and the season when they occur. Reservoirs can benefit downstream water quality by trapping sediment and potential pollutants, while worsening levels of other constituents such as dissolved oxygen. The effects reservoirs have on water quality are evident when comparing data from upstream and downstream (i.e., at USGS gages) of the impounded waters (Anderholm et al. 1995). Reservoirs have a major influence on suspended sediment and turbidity levels in the Rio Grande Basin. There are noticeable differences in the values of these constituents downstream of Abiquiu, Cochiti, and Elephant Butte reservoirs, which sequester the turbid and suspended-sediment-rich waters, causing the suspended particles to settle to the reservoir bottom. Overall, the connectivity between upstream and downstream reaches is fragmented, affecting the transport of suspended matter and nutrients and thus water quality for aquatic communities (Tracy and Thompson 2002).

3.4.1 General Conditions and Data Availability

No studies have researched extensively the effect reservoirs have on nutrients in the Rio Grande watershed. However, historical data show that nutrient concentrations decrease significantly in reservoirs due to nutrient uptake in these water bodies (Levings et al. 1998, Moore and Anderholm 2002). For this reason only Cochiti and Abiquiu Reservoirs were used in the analysis. Elephant Butte is included to reflect recent research concerning mercury and hydrogen sulfide within the reservoir. There is a continued need for additional research concerning water quality in and above and below Rio Grande Basin reservoirs.

3.4.2 Abiquiu Reservoir

Abiquiu Dam is in a 350-foot-deep canyon on the Rio Chama about 32 miles upstream from the confluence of the Chama and the Rio Grande. The reservoir's functions are flood control, water supply, flood retention, and recreation. The water is stored for agricultural, municipal, and industrial uses. Data analysis shows seasonal and temporal changes within the reservoir and upstream and downstream of the dam. The datasets used to analyze the changes were from the U.S. Army Corps of Engineers (USACE) (1978-1998) and from USGS gages. The gage data were instrumental in analyzing upstream and downstream change, allowing the WQRT to track constituents as they move through the reservoir. The USACE data, collected at various locations within the reservoir and at the outflow from the dam, were scattered, with monthly periods when data collection was continuous and breaks when collection was absent for years at a time. . These data did, however, provide the WQRT with an understanding of how certain constituents change with reservoir depth.

Tables M-7a and M-7b summarize the completed analysis for Abiquiu Reservoir from the USGS gage data. For purposes of the analysis, changes upstream and downstream of the reservoir were compiled for three seasons of four months each: winter (November, December, January, February), spring (March, April, May, June), and summer (July, August, September, October). Table M-7a contains data for dissolved oxygen (DO), hardness (Hard), and pH. Table M-7b shows levels of fecal coliform (FC), conductivity (Cond), and temperature (Temp). Each table shows average values by season at inflow and outflow locations, change between inflow and outflow data (a negative value indicates the constituent value is higher at the gage above Abiquiu Reservoir), overall average of the constituent, high and low values recorded, and the range.

Table M-7a. Summary Analysis for Abiquiu Reservoir Using USGS Gage Data

Season	DO In	DO Out	DO Change	Hard In	Hard Out	Hard Change	pH In	pH Out	pH Change
Winter	10.30	10.70	0.40	260.42	221.00	-39.42	7.54	7.79	0.25
Spring	10.10	10.50	0.40	221.64	214.64	-7.00	7.79	7.76	-0.03
Summer	7.89	7.55	-0.34	183.06	189.59	6.53	7.82	7.65	-0.17
Overall	9.20	9.30	0.10	217.21	206.51	-10.70	7.74	7.72	-0.02
High	16.00	19.50		800.00	370.00		8.70	8.50	
Low	5.20	2.80		15.00	100.00		6.60	6.30	
Range	10.80	16.70		785.00	270.00		2.10	2.20	

Table M-7b. Summary Analysis for Abiquiu Reservoir Using USGS Gage Data

Season	FC In	FC Out	FC Change	Cond In	Cond Out	Cond Change	Temp In	Temp Out	Temp Change
Winter	45.65	43.53	-2.12	1.61	1.01	-0.60	5.43	5.96	0.53
Spring	29.86	30.41	0.55	1.12	1.29	0.17	10.87	9.12	-1.75
Summer	33.93	38.20	4.27	1.28	1.44	0.16	19.64	15.58	-4.06
Overall	35.01	36.50	1.49	1.28	1.29	0.01	13.18	11.03	-2.15
High	100.00	100.00		15.00	4.00		25.00	24.30	
Low	0.00	0.00		0.01	0.02		-3.00	-1.00	
Range	100.00	100.00		14.99	3.98		28.00	25.30	

At both inflow and outflow locations, dissolved oxygen was highest during winter months and decreased as air and surface water temperature warmed with the changing seasons (Figure M-8). However, the range between the highest and lowest recorded levels of DO is much higher at outflow (16.7 mg/L) than at inflow (10.8 mg/L). Thus, the natural inflow of dissolved oxygen from the Rio Chama does not vary as much as the regulated outflow from the reservoir. For the entire data set, however, there is virtually no difference in average annual dissolved oxygen values, with inflow at 9.2 mg/L and outflow at 9.3 mg/L.

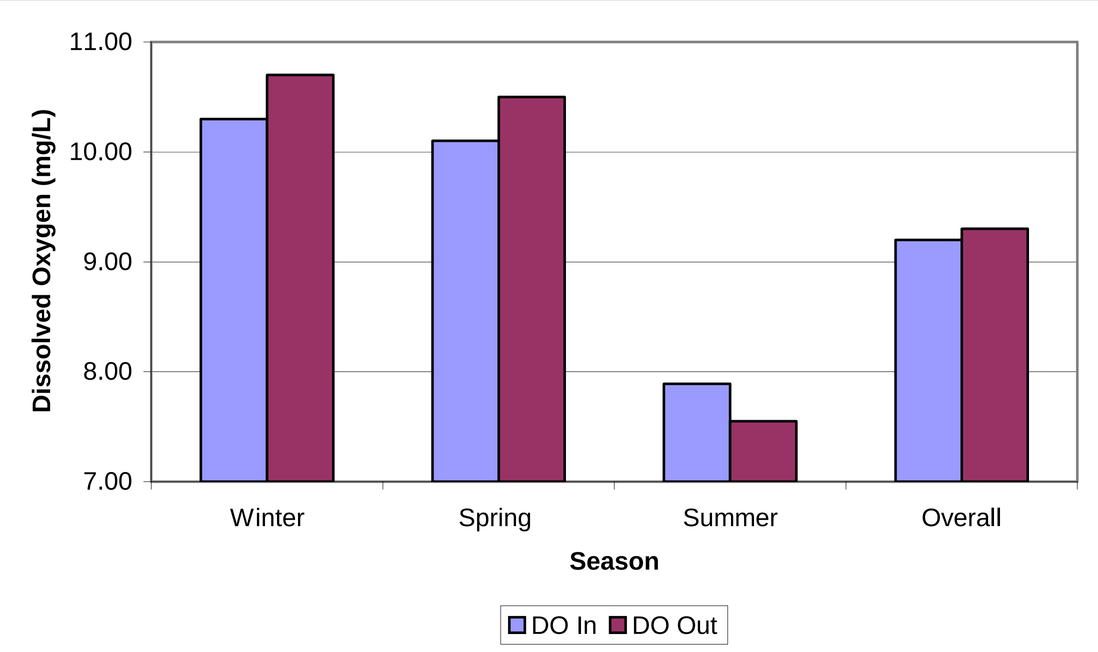

Figure M-10. Average dissolved oxygen at inflow and outflow locations by season for Abiquiu Reservoir.

Hardness values at inflow were highest during Winter and decreased during Spring and Summer (Table M-7a; Figure M-11). The pattern was similar at outflow. Although there is a slight variation in hardness between the inflow and outflow locations, annual averages for Abiquiu Reservoir are very similar... However, the range between the highest and lowest hardness values at inflow is 800 mg/L, while it is 370 mg/L at outflow.

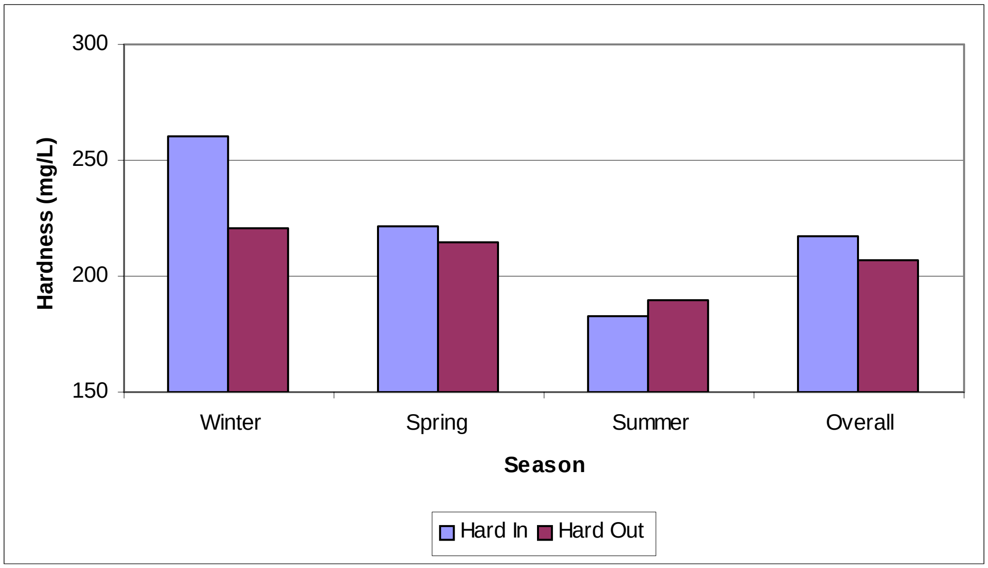

Figure M-11. Average hardness at inflow and outflow locations by season for Abiquiu Reservoir.

Average values for pH and fecal coliform are essentially the same for inflow and outflow locations, and the ranges are similar as well (Figure M-12). One noticeable difference in pH occurred between two time periods: 1975-1984 and 1985-1998. The average pH values during the 1975-1984 period were 7.22 at inflow and 7.46 at outflow, while average pH values during the 1985-1998 period were 8.21 at inflow and 8.18 at outflow. Fecal coliform concentrations were highest during winter for both inflow and outflow locations (Figure M-13).

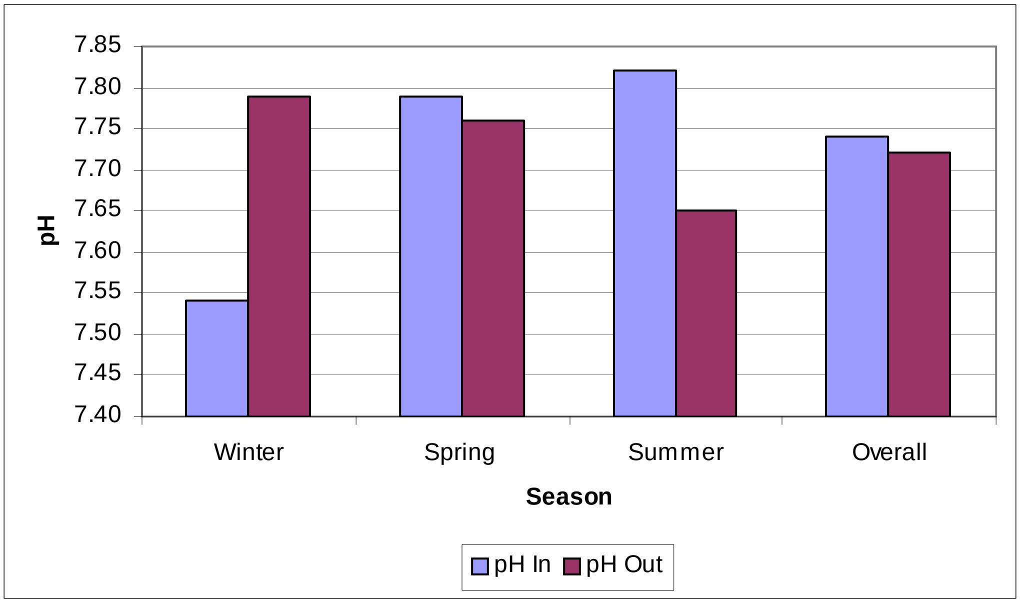

Figure M-12. Average pH at inflow and outflow locations by season for Abiquiu Reservoir.

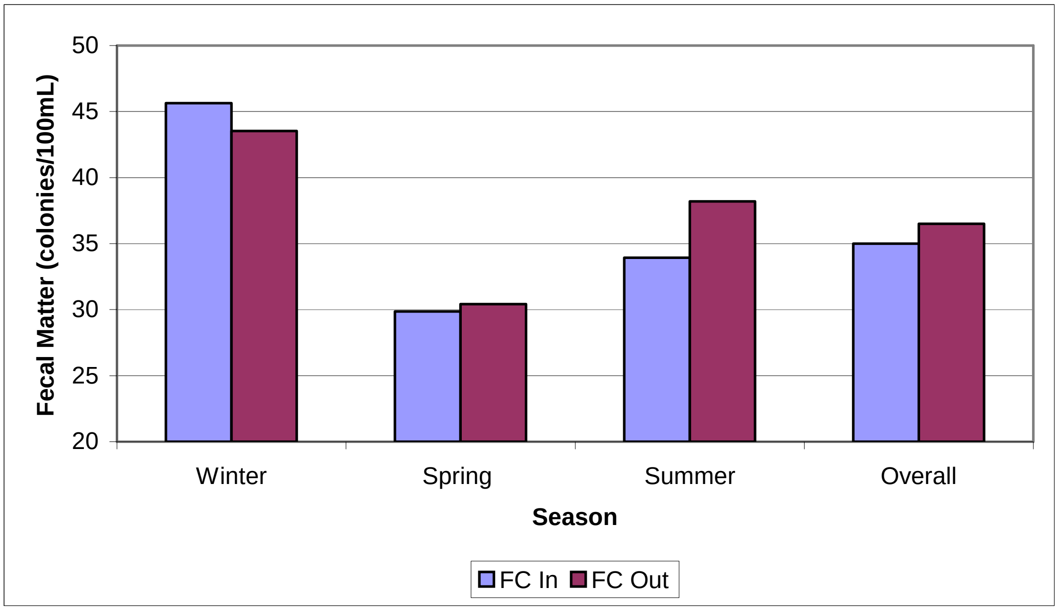

Figure M-13. Average fecal content at inflow and outflow locations by season for Abiquiu Reservoir.

In spring and summer, water temperature as expected was lower at outflow than at inflow (Figures M-14 through M-16). Temperatures were highest during summer, when there was a difference of 4.06º C between outflow and inflow. Temperatures at inflow and outflow were similar during winter, although slightly higher at outflow. Average temperatures for the year were higher at inflow than at outflow. Higher water temperatures during warmer months act synergistically with lower dissolved oxygen levels, creating adverse affects on organisms downstream (Army Corps of Engineers 2001).

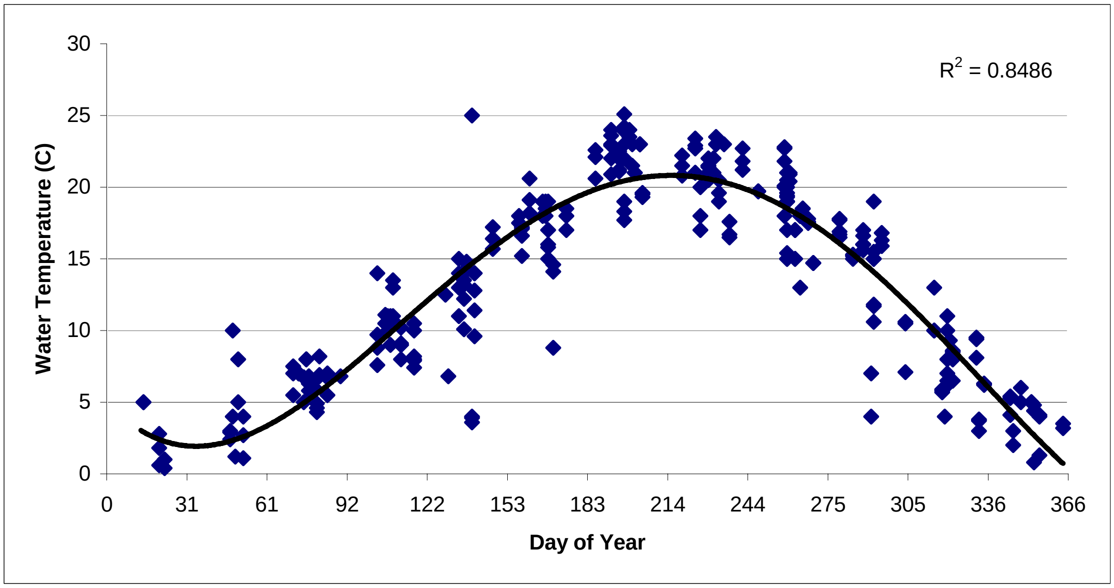

Figure M-14. Surface water temperature correlation plot for Abiquiu Reservoir.

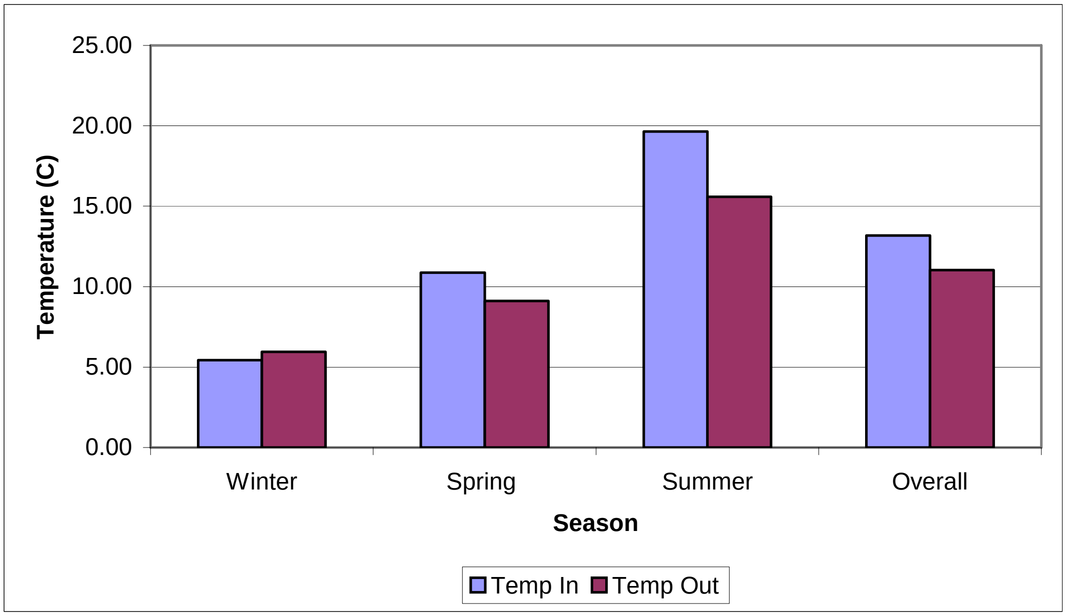

Figure M-15. Average surface water temperature at inflow and outflow locations by season for Abiquiu Reservoir.

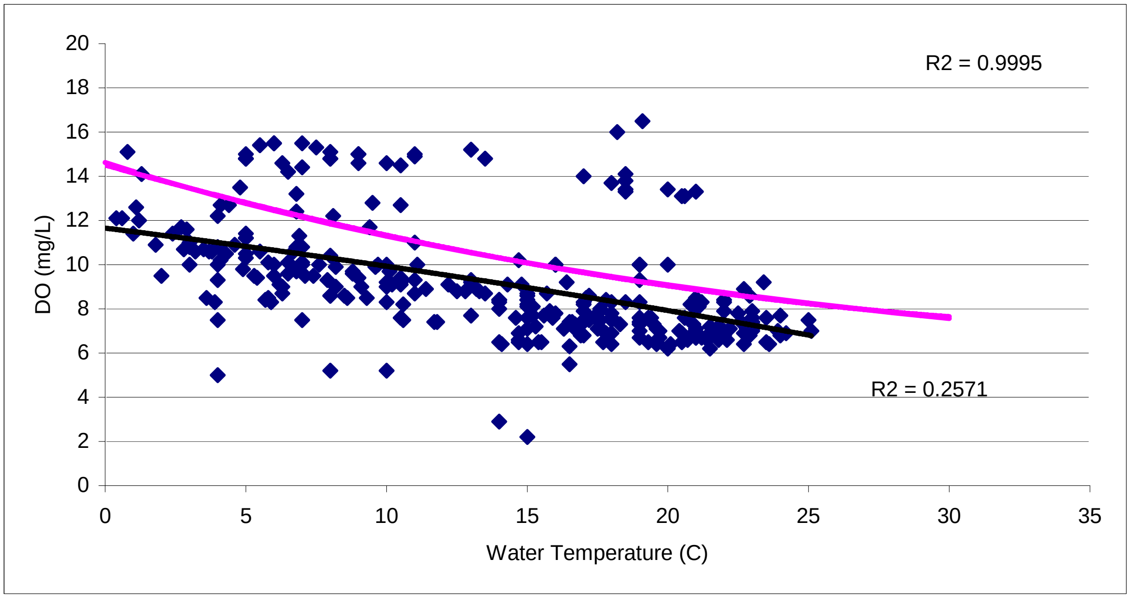

Figure M-16. Dissolved oxygen and surface water temperature correlation plot for Abiquiu Reservoir.

3.4.3 Cochiti Reservoir

Cochiti Reservoir was constructed in 1973 to serve as a flood and sediment control dam for the middle Rio Grande. A small recreational pool is maintained with San Juan–Chama water. Water quality studies that focus on Cochiti Reservoir are nonexistent. U.S. Army Corps of Engineers data for Cochiti Reservoir cover a short time period (1991-1999), at various locations on and immediately below the reservoir (Table M-8). Since USGS gage data are lacking immediately upstream and downstream of Cochiti Reservoir, the USACE data were used for this analysis. Los Alamos has recently completed analysis on plutonium within the reservoir, which has acted as a trap for materials coming from Los Alamos Canyon (Rickman 1997), including plutonium 239 and 240. The Los Alamos study shows that while plutonium is attached to sediments at the bottom of the reservoir, no plutonium has leached into the reservoir water or fish. Cochiti Reservoir sediments are much thicker than those in Abiquiu and El Vado Reservoirs; Elephant Butte Reservoir sediment deposits are similar (Rickman 1997).

Table M-8. Summary Analysis for Cochiti Reservoir Using U.S. Army Corps of Engineers Data

	DO In	DO Mid	DO Out	DO Change	pH In	pH Mid	pH Out	pH Change
Overall	7.24	7.50	9.55	2.41	8.09	8.15	8.00	-0.09
High	9.30	8.70	13.50		8.60	8.90	8.90	
Low	4.20	5.10	5.90		6.70	7.60	6.80	
Range	5.10	3.60	7.60		1.90	1.30	2.10	

	FC In	FC Mid	FC Out	FC Change	Temp In	Temp Mid	Temp Out	Temp Change
Overall	28.75	0.57	5.63	-23.12	17.29	18.09	16.80	-0.49
High	100.00	2.00	25.00		25.30	25.70	28.00	
Low	1.00	0.00	0.00		3.10	5.00	5.00	
Range	99.00	2.00	25.00		22.20	20.70	23.00	

The USACE data for Cochiti Reservoir were recorded on the same day at three locations: inflow (In), middle of the reservoir (Mid), and immediately downstream of the reservoir (Out). Constituents measured were dissolved oxygen (DO), pH, fecal content (FC), and surface water temperature (Temp). The purpose of the analysis was to identify any spatial changes in constituents throughout the reservoir and any impact the reservoir may have on the constituents.

For dissolved oxygen and pH, all measurements were taken at the surface. Average dissolved oxygen (Figure M-17) changed dramatically between the inflow, middle, and outflow locations, rising 2.31 mg/L from inflow to outflow, demonstrating that dissolved oxygen levels rise as a result of the dam and reservoir. Values for pH did not differ significantly by location (Figure M-18). One noticeable difference was that the values were higher at Cochiti than at Abiquiu, although Abiquiu data recorded over the same temporal period were similar.

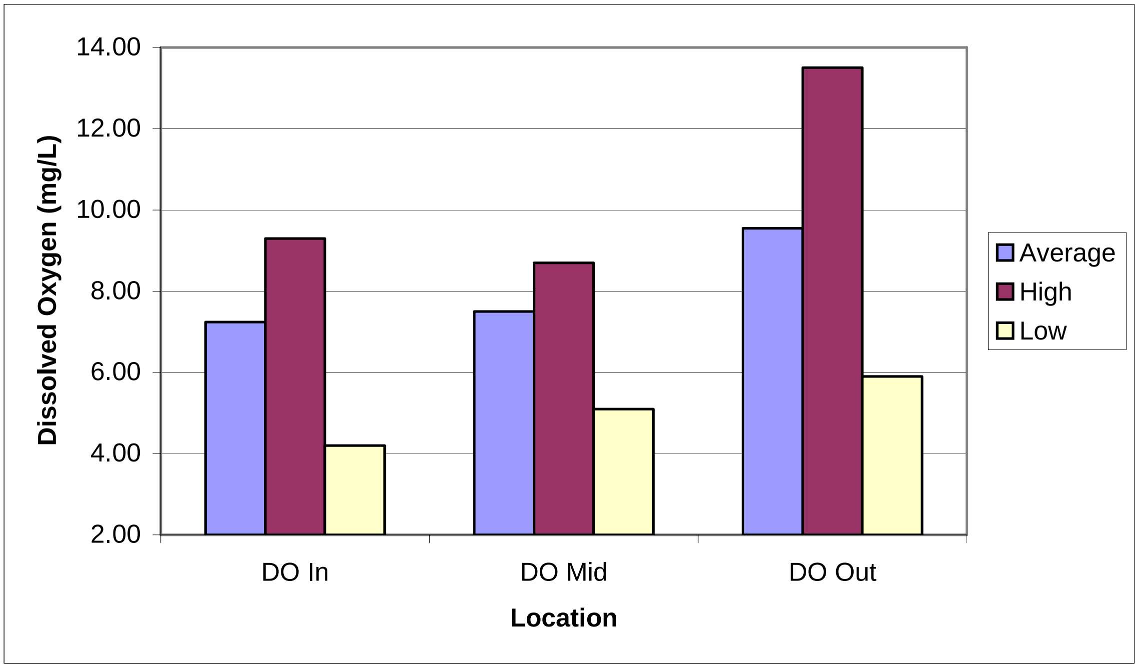

Figure M-17. Average dissolved oxygen by location for Cochiti Reservoir.

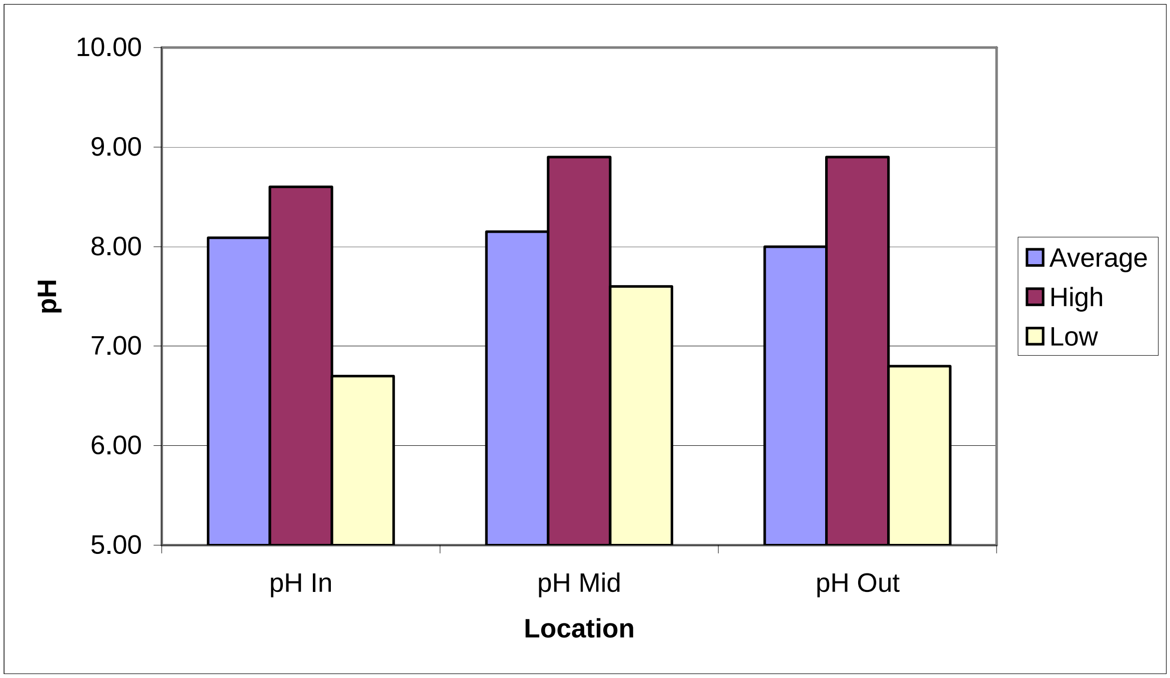

Figure M-18. Average pH by location for Cochiti Reservoir.

Fecal content varied by location (Figure M-19), although fecal values were not extremely high compared to values found in other reaches of the Rio Grande. Counts were much lower at outflow than at inflow, and almost nonexistent at the middle location. This distribution suggests that much of the fecal material present in a reservoir may be not be measurable at the surface because it has settled to the bottom. The higher values downstream of Cochiti Reservoir may be related to the bottom-releases associated with the dam. Surface water temperatures changed throughout the reservoir, with the highest values in the middle (Figure M20) and the lowest at outflow. This pattern is similar to what is seen in most large bottom-releasing reservoirs. The inflow temperatures are colder than the middle temperatures because flowing Rio Grande water is contributing to the inflow area and coldest at outflow because the discharge comes from the hypolimnion.

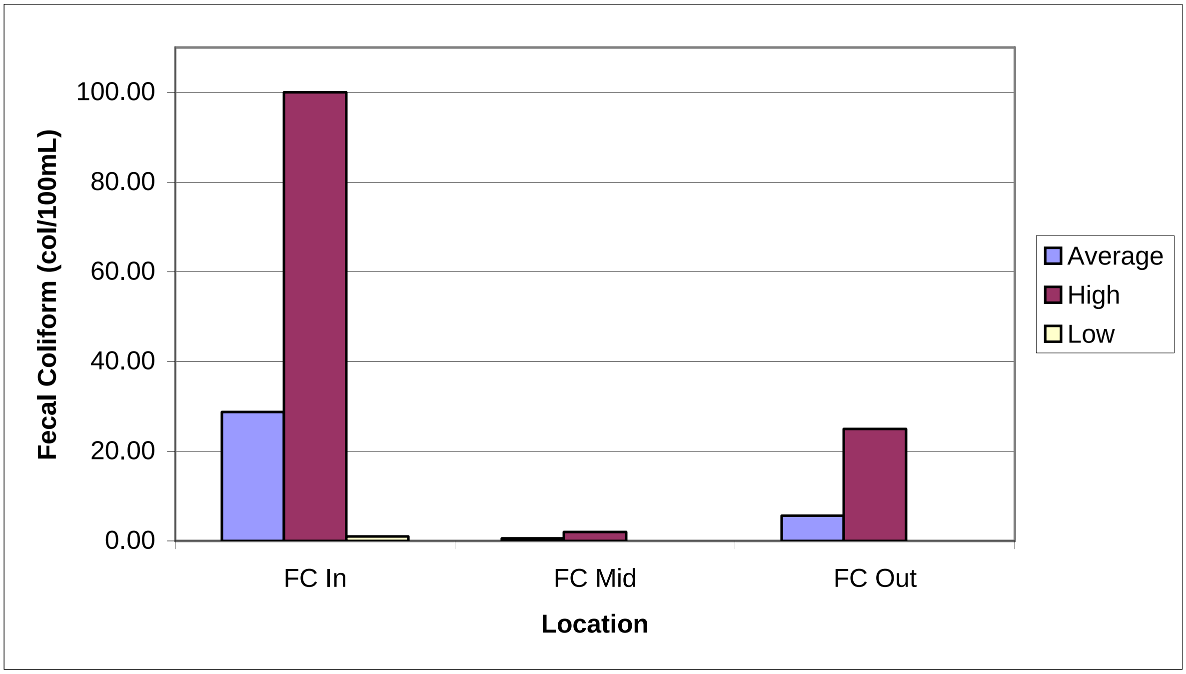

Figure M-19. Average fecal content by location for Cochiti Reservoir.

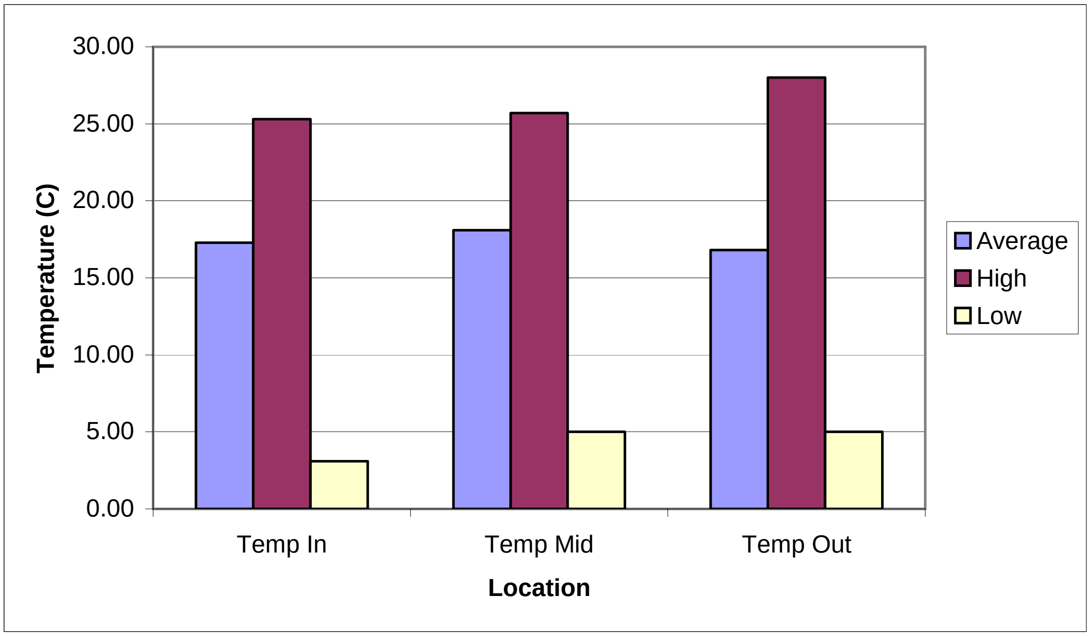

Figure M-20. Average surface water temperatures by location for Cochiti Reservoir.

3.4.4 Elephant Butte Reservoir

Very little data are available by which to accurately characterize water quality in Elephant Butte Reservoir. Comparing data collected at upstream and downstream USGS gages is nearly useless because of the distance between the San Marcial gage and the gage below Elephant Butte Dam. Government agencies or academic researchers through individual field efforts conducted to characterize a specific constituent collected the data used. Two constituents that have been recently researched at Elephant Butte Reservoir are hydrogen sulfide (H_2S) and mercury (Hg).

Very few data were available for hydrogen sulfide in the Rio Grande Basin. However, recent studies on Elephant Butte Reservoir indicate that hydrogen sulfide loads are problematic during summer months when the hypolimnion of the reservoir becomes anoxic. Conditions suitable for the generation of hydrogen sulfide may only occur when the reservoir is at relatively high storage levels and mixing does not occur in the lower levels of the water body. Releases of water with high levels of hydrogen sulfide may contribute to the lower pH levels observed below the dam when dissolved oxygen levels are low. When hydrogen sulfide comes in contact with oxygen in the outlet works of Elephant Butte, it may react with the oxygen and produce low levels of sulfuric acid, causing a decrease in pH. During stratification, hydrogen sulfide accumulates and persists until fall turnover. According to Canavan (1999), at that time hydrogen sulfide is circulated into the epilimnion, oxidizes, and is precipitated out as sulfate (SO_4). Hydrogen sulfide in the hypolimnion does not pose a large problem for the reservoir because it remains isolated. The problem begins when water is released downstream, potentially impacting water and air quality. A survey of fish downstream of Elephant Butte Dam (reported by Jacquez in Canavan 1999) found almost no fish for 22 miles below the dam, to Caballo Reservoir. The source of the hydrogen sulfide in Elephant Butte Reservoir is not known; it may come from geothermal underground springs entering the hypolimnion or from internal microbial processes (Canavan 1999).

Mercury and dissolved monomethylmercury (CH_3Hg^++) are water quality issues in this reach of the Rio Grande as well. Elephant Butte and Caballo Reservoirs are known to have high levels of mercury (Johnson 1995). Johnson considered potential sources of mercury in the reservoirs to be coal plants, atmospheric deposition, and mine wastes. Mercury is most likely transported to rivers by overland flow. Caldwell and Canavan (1998) found that dissolved monomethylmercury increased in Elephant Butte Reservoir from July 1996 to October of 1996. During the same time period, concentrations in the reservoir were less than the detection limits. Canavan (1999) also found that alkalinity, calcium (Ca), and hardness increase in depth following the start of stratification in Elephant Butte Reservoir.

3.5 Long-term and Seasonal Trends

An analysis of water quality based on seasonal flow was necessary to demonstrate the natural changes among constituents throughout the year. Knowledge of seasonal trends in water quality can aid in the interpretation of extremes and variations in the data. By organizing the data into three seasons (November through February, March through July, August through October), we were able to detect natural and anthropogenic changes spatially and temporally throughout the Rio Grande Basin. The grouping of the seasons was designed to capture periods of baseflow, runoff, and interflow.

The selected USGS gages and associated data were used for seasonal flow analysis. The data were imported into a geographic information system (GIS), and seasonal flow maps were generated in ESRI's ArcGIS environment. The classification system for the maps is based on the Jenks Natural Breaks method, which creates classes based on natural optimum breaks in the data. The following sections discuss seasonal trends by constituent and gage.

3.5.1 Water Temperature

Human activities do not substantially alter natural fluctuations in water temperature through the seasons. However, surface water temperatures measured directly downstream from dams are known to be lower than upstream values because of the effects of bottom-releasing dams. Depending on the location of the water being released from the reservoir, downstream temperatures may be extremely variable in comparison with upstream values (USEPA 1987).

The highest temperatures, measured at gages downstream of Albuquerque (Central Section) and averaging over 20°C, occurred during Season 3 (summer) (Map M-2). The lowest surface water temperatures were recorded in the Northern and Chama sections during Season 1 (winter). The above Abiquiu Reservoir gage on the Rio Chama recorded consistently low temperatures during each of the three seasons, with the lowest temperature values during Seasons 2 (spring) and 3. No substantial differences in temperature were noticed between the inflows and outflows at the gages near Abiquiu, Cochiti, and Elephant Butte Dams. However, these gages are not located directly above and below the dams, and it is therefore difficult to assess what impact the reservoirs have on water temperature within the Rio Grande system. Yet, at each location, the downstream gage had a higher surface water temperature, indicating that water temperatures in the Rio Grande Basin are influenced primarily by natural processes (e.g., latitude or air temperature).

3.5.2 Dissolved Oxygen

The available data indicated that levels of dissolved oxygen vary greatly by season throughout the Basin (Map M-3). (Data from the above Abiquiu Reservoir gage during Season 1 and the below Abiquiu gage during Season 3 were insufficient for analysis; all other gages had adequate data.) The lowest dissolved oxygen values correlated directly with higher air and water temperatures and were recorded during the warmest time of the year, decreasing at each gage from Season 1 to Season 3. In addition, the Northern Section gages had noticeably higher dissolved oxygen levels than the gages in the San Acacia and Southern sections.

The data from the gage below Elephant Butte Dam did not fit the seasonal patterns observed at other gages. The Elephant Butte Dam gage had the highest dissolved oxygen level (11.71 mg/L) during Season 1 and the lowest during Seasons 2 and 3 (6.94 and 4.99 mg/L). Reservoir operations have a large impact on the fluctuation of dissolved oxygen within the system. Dissolved oxygen values at the nearest gage above Elephant Butte Dam (San Marcial) were very different than those recorded at the gage below the dam. Large variations were observed, especially as the seasons progressed and water and air temperatures increased. The extreme variations in dissolved oxygen caused by Elephant Butte Reservoir were not observed near Cochiti or Abiquiu Reservoirs. No other gage had average dissolved oxygen readings below 7.4 mg/L during any season.

3.5.3 Total Dissolved Solids

Total dissolved solids (TDS) are lowest in the upper reaches of the Rio Grande Basin and highest in the middle and lower reaches. The Northern and Chama section gages have relatively low TDS (100.01-300.00 mg/L) and have consistent values throughout each of the seasons (Map M-4). There are insufficient data for all seasons for the gages above and below Abiquiu Reservoir r and for the floodway at San Acacia during Season 3. There is an influx of TDS at the Jemez River gage during each season, yielding higher TDS values there than at the gages above and below the confluence of the Jemez River and the Rio Grande during each flow season. The Jemez contributes large quantities of dissolved solids to the Rio Grande, as indicated by the high values measured at the gages. Below the Albuquerque gage, where the TDS levels are between 100 and 300 mg/L during each flow season, TDS increases. There is a slight seasonal increase at the Bernardo gage during all seasons, but considerable increases are measured at San Acacia and San Marcial, especially during Season 3. TDS decreases again as the river flows through Elephant Butte Reservoir (gages above and below Caballo Dam have high TDS values during each flow season), indicating that Elephant Butte Dam lowers the amount of TDS in the system. This is not a drastic seasonal decrease, but it is a noticeable one.

The highest TDS values in the Rio Grande Basin are found at the El Paso and Fort Quitman gages. Readings at these gages are consistently high throughout each of the flow seasons, with Fort Quitman showing higher averages than any other gages in the system. Thus, a large amount of total dissolved solids is being added to the system downstream from Leasburg Diversion Dam and the City of El Paso. The highest TDS readings throughout the system are measured during Seasons 1 and 3, while the lowest are measured at most gages during Season 2 (higher flows assist in reducing TDS). Cochiti Dam did not affect TDS levels. No conclusions were drawn from TDS levels associated with Abiquiu Dam, as the data were insufficient for analysis. Settling in Elephant Butte Reservoir causes a significant decrease in TDS. In general, a large dam like Elephant Butte has a significant impact on TDS, while dams of smaller magnitude such as Cochiti may have no impact or a small one.

3.5.4 pH

A pH range of 6.0 to 9.0 is ideal for invertebrates and freshwater fish. Above and below this range, there may be adverse affects. Data at the above Abiquiu Reservoir gage during Season 1 and the below Abiquiu Reservoir gage during Season 3 were insufficient for analysis. At all other gages, pH values were between 7.88 and 9.00 during each of the three flow seasons, with latitudinal and seasonal variability (Map M-5). Seasonal trends include a decrease in pH values from Season 1 to Season 2, a decrease or similar values in lower reaches from Season 2 to Season 3, and an increase or similar values in the upper reaches from Season 2 to Season 3. The highest pH values were recorded on the Rio Chama at the above Abiquiu Reservoir gage in Seasons 2 and 3.

3.5.5 Turbidity

Data were insufficient at the above Abiquiu Reservoir gage and the Jemez River below Jemez Canyon Dam gage during each season, and at the Leasburg Dam gage during Seasons 2 and 3. Turbidity varies by season and latitude throughout the system. The lowest turbidity values are recorded during Season 1 (Map M-6), and the highest values occur during the warmer summer months. Turbidity increases down the length of the Rio Grande from the Northern Section to the inflow at Elephant Butte Reservoir, where the dam alters turbidity downstream. Turbidity is highest in the San Acacia Section of the Rio Grande study area. The Rio Puerco drains the largest area (6,057 mi^2) within the Upper Rio Grande and contributes large amounts of sediment during precipitation events and snowmelt. The Rio Salado, which drains an area of 1,394 square miles, also contributes large amounts of sediment to the Rio Grande system. Turbidity below Elephant Butte Dam is relatively low during each season, while values above the dam are much higher. Turbidity is again high downstream of the Leasburg Diversion Dam, especially from El Paso to Fort Quitman, during seasons 2 and 3.

The Rio Grande above the Otowi gage is a gaining stream with consistent flows. Downstream of the Otowi gage, the Rio Grande is a losing stream. Below the City of Albuquerque the majority of inflow to the Rio Grande is supplied by seasonal ephemeral flows. During large precipitation events, large quantities of sediment are transported to the river at high velocities. Therefore, turbidity is higher in the middle reaches during the rainy season and periods of snowmelt. The turbidity levels below Elephant Butte Dam are consistent low throughout the year, indicating that reservoir operations there lower turbidity levels. However, variations in turbidity values are not seen near Abiquiu Reservoir or Cochiti Reservoir.

3.5.6 Suspended Sediments

There are insufficient data from the Fort Quitman gage during each flow season. All other gages have sufficient data for each season. Suspended sediment load in the Rio Grande depends on the seasonality of flow and is positively correlated with stream flow. Thus, during seasonally high flows, from snowmelt and the rainy season for example, sediment values are higher. The middle reaches of the system have the highest average values of suspended sediments, with the two San Marcial gages (floodway and conveyance) having the highest values (Map M-7). These values are recorded during Season 3, although increases in suspended sediments are seen at other gages throughout the year. The high suspended sediment values likely result from storm events and sediment discharged into the Rio Grande via the Rio Puerco and Rio Salado. The lowest values are found at the Lobatos gage (Northern Section) and the gage below Elephant Butte Dam. The Lobatos gage receives very little sediment input, and suspended particles settle in Elephant Butte Reservoir, dramatically decreasing suspended sediments below Elephant Butte Dam in comparison to the values at the San Marcial gages above the reservoir.

Overall, suspended sediments increase from north to south in the Rio Grande Basin to Cochiti Dam. At that point, settling in Cochiti Reservoir causes a decrease in suspended sediments. Suspended sediment values then increase from below the confluence with the Jemez River to Elephant Butte Reservoir. After the immediate decrease below Elephant Butte Dam, suspended sediments increase again downstream. There is no noticeable change in suspended sediments above and below Abiquiu Reservoir.

3.5.7 Specific Conductivity

Data from the Fort Quitman gage are insufficient during each flow season; all other gages have sufficient data for each season to assess seasonal fluxes in conductivity. Low conductivity values (less than 600 μs/cm) were found at each gage above Cochiti Dam during all three seasons, with the lowest values being recorded at the Taos Junction gage (Northern Section) (Map M-8). Higher conductivity values were found in the middle to lower reaches of the Rio Grande Basin, including along the Jemez River above the confluence with the Rio Grande and downstream of the confluences with the Rio Salado and Rio Puerco. The Jemez River gage has higher values than surrounding gages during each season, reaching average conductivity values of 1,534.81μs/cm during Season 1. The Jemez River drains a basaltic landscape, which is high in mineral content. Thus, the Jemez River appears to be a large contributor of minerals and ionic compounds to the Rio Grande Basin. However, the gages downstream of the Jemez River confluence do not have high conductivity readings.

The gages along the Chama Section show consistently low conductivity readings throughout each season, with very little seasonal change. Outside of the Jemez River gage, the Southern Section has the highest conductivity values. In addition, the reservoirs appear to have no impact on conductivity. There is no noticeable difference in conductivity upstream and downstream of the three major reservoirs in any of the seasons.

3.5.8 Fecal Coliform

Seasonality largely determines fecal content in surface water. Fecal coliform levels increase at higher temperatures, and fecal material is more likely to run off surfaces during the rainy season. Agricultural practices, including the application of fertilizer containing feces and livestock waste, also contribute to fecal contamination. High temperatures, runoff, and agricultural applications occur during Seasons 2 and 3, and the highest fecal coliform counts thus occur during spring and summer.

Data for fecal coliform within the Rio Grande Basin are sporadic, but the available data allow an interpretation of local variances in fecal coliform counts. Data are insufficient at the following locations: above Abiquiu and below Abiquiu (all seasons); Jemez River, Bernardo, and Leasburg Dam gages (all seasons); and the Albuquerque gage during Season 1. Fecal coliform counts are highest in the middle and lower reaches of the system (Map M-9). The Lobatos and Taos Junction gages (Northern Section) have relatively low fecal coliform counts through each of the flow seasons (0.01 to 400.00 col/100 mL of water). The area surrounding these gages is relatively undeveloped, and agricultural activity is low. Fecal counts increase significantly at the Otowi gage, decrease at the San Felipe and Albuquerque gages, then increase again at the San Acacia gages. The confluence with the Rio Puerco may cause the increase in fecal counts noticed at San Acacia. At the San Acacia and San Marcial gages, fecal content, on average, is above 200 colonies during each flow season and is consistently above 1,000 colonies. Two of the highest measured averages (above 3,500 colonies) occur at the floodway at San Acacia (4,117.25 colonies) and the floodway at San Marcial (3,573.00 colonies) during Season 3. At the Elephant Butte gage, fecal content is again low (less than 50 colonies during each flow season), indicating that the dam causes fecal matter to settle in the reservoir. Downstream of Elephant Butte and Caballo dams fecal matter is again high. At the El Paso and Fort Quitman gages, fecal content is consistently around 1,000 colonies during each of the three flow seasons, which may be directly correlated with wastewater inflows.

Overall, fecal coliform counts along the Rio Grande are relatively low to the Otowi gage, where there is a sharp increase; decreases to Albuquerque before increasing dramatically at San Acacia and San Marcial; and decreases abruptly below Elephant Butte Dam Fecal coliform is highest during Season 3 and lowest between Seasons 1 and 2. Although fecal matter content is lower below than above Cochiti Dam, it, it is most likely not a good indicator of how the dam affects fecal content within the system (fecal content is higher below the dam during Season 3). The distance between the gages is too great to make an accurate assessment. There is a sharp decrease in the average amount of fecal matter at the gage below Elephant Butte Dam in comparison to the average amount of fecal matter in the gages above the dam.

3.5.9 Other Constituents

Because of the number of gages with insufficient data, levels of arsenic, mercury, and carbon dioxide were not mapped by seasonal flow. However, some variation between gages was noted.

3.5.9.1 Arsenic

Data from the gages above Abiquiu Reservoir, below Abiquiu Reservoir, at Leasburg Dam during Season 2, and at Fort Quitman were insufficient for analysis. Overall, arsenic levels remain consistent throughout the year with little variation. Levels at the Jemez River gage are high throughout the year, indicating that the Jemez adds a noticeable amount of arsenic to the system from the basaltic terrain in this drainage. Arsenic levels above the Jemez–Rio Grande confluence are lower than at the Jemez River gage and below the confluence they are higher. There are no noticeable differences in connection with the dams and reservoirs, and seasonal trends are not easily identified. Overall, arsenic levels are lower in the upper reaches of the Rio Grande and higher in the lower reaches, which may be due to more agricultural activity in the south.

3.5.9.2 Mercury

Data are insufficient at the gages above Abiquiu Reservoir, below Abiquiu Reservoir, on the Jemez River, on the Rio Grande at Albuquerque (Season 3), at Leasburg Dam (Seasons 1 and 3), and at Fort Quitman. The only areas with sufficient data are in the middle and upper reaches of the system, with the highest values recorded between Otowi and San Marcial. Levels of mercury are high (0.21-0.40 μg/L) at Otowi throughout the year and are highest at San Marcial during Season 3. Mercury values below dams are lower than above dams. Although data are lacking near Abiquiu Dam, values are higher above Cochiti and Elephant Butte dams and lower below the dams during each flow season. These data indicate that the dams play a key role in mitigating the amount of mercury in the system. There is no direct seasonal association, but the highest values are measured during Seasons 2 and 3.

3.5.9.3 Carbon Dioxide

Data on carbon dioxide are insufficient from the gage above Abiquiu Reservoir. It is difficult to distinguish trends among the rest of the gages. Similarities can be discerned between the gages on the Rio Grande near Lobatos, below Taos Junction Bridge, and on the Rio Chama near Chamita. Carbon dioxide levels are 1-2 mg/L during Seasons 2 and 3 but vary during Season 1; they are highest for many gages during Season 1 and then decrease to Season 3. The gages on the Rio Grande at Otowi Bridge and San Felipe and on the Jemez River record 1-3 mg/L during each flow season. Readings from the gage below Elephant Butte Dam vary greatly throughout the flow season, with the highest (6.52 mg/L) recorded during Season 3. At Fort Quitman carbon dioxide levels fluctuate between 3 and 13 mg/L, with the highest average value during Season 3.

Seasonal changes in carbon dioxide levels are difficult to distinguish. Higher values tend to occur during Season 1 and Season 3, and lowest values typically are in Season 2. Average carbon dioxide levels vary below the dams, with readings <1 below Abiquiu Dam, increasing, increasing slightly below Cochiti Dam, and varying between 1.41 and 6.52 mg/L below Elephant Butte Dam.

4.0 DEVELOPMENT OF UPPER RIO GRANDE BASIN SURFACE WATER QUALITY MODELS

Following publication of the Draft EIS, some questions were raised by technical reviewers regarding the regression analyses presented in Appendix M that contributed to the criteria used for ranking alternatives. In response to these concerns, the USGS member of the Water Quality Technical Team revised the regression analysis by adding some reservoir storage data, upstream inflows, and changes in the use of independent and dependent variables. The purpose of this limited reanalysis was to try to improve the explanation of the variation in the three water quality constituents (dissolved oxygen, water temperature, total dissolved solids) used as criteria for ranking alternatives. After adding upstream inflows at each site, sometimes lagged up to three days when warranted by upstream distance, a revised regression analysis was developed. After comparison with the original regression model simulations, little difference was noticed and the conclusions summarized in Chapter 5 of this appendix, as well as in Chapter 4 of the EIS, remain unchanged. The revised regression analysis is included as an Addendum at the end of this appendix, in which some updated tables and graphs are presented.

4.1 Introduction

In river systems, including the Rio Grande, the boundary conditions that govern water quality include both environmental and anthropogenic factors. For example, environmental factors such as climate, air quality, geology, and biology can affect the water quality in a river system. Anthropogenic factors such as point source and non-point source inputs of pollution also influence the water quality of a system. To explain the observed variation, numerical models can be used to simulate natural conditions and to predict how water quality variables in a given system will respond to changes in boundary conditions.

Spatial variability of water quality is an important consideration for numeric models. Throughout a given river system, a change in location may result in a change in boundary conditions. For example, location within a river system can determine the amount of water entering the stream channel. The amount of water entering a stream from direct runoff in response to a precipitation event or by ground water inflow, determines the water budget of the system, and in turn affects the quality of surface water. Differences in physical basin characteristics such as the angle of the channel slope or the thickness or composition of surrounding bedrock or surficial deposits can cause a change in erosion-sediment yield. As a result, different locations within the Project Area can have environmental characteristics that may affect surface water quality differently from one location to the next.

Dam releases and water storage can influence water quality in a system, regardless of whether climate, air quality, geology, and biology are held constant. Dams within the Project Area, which are used to control the release and storage of surface water within the system, add to the inherent stream discharge variability. The annual average of mean daily discharge at locations throughout the project area illustrates the spatial variability of stream discharge. At a given stream gage, mean annual stream flow can vary from year to year, which could affect water quality variables. Short-term and seasonal variations of water quality resulting from changes in boundary conditions also affect water quality.

To estimate the response of selected water quality variables to spatial and temporal changes in environmental conditions, numeric, models were developed at locations distributed throughout the project area ((see Map 1-1 of EIS)). To develop these models, historic data from 1975 to 2001 were loaded to a project database from federal and state water quality and climate data sources. Data in the project database provided an efficient and accessible method for storing, filtering, and analyzing water quality data.

4.2 Water Quality Database Development

Historical surface water quality and stream discharge data were collected from stream gages within the project area, including tributary streams. Data were obtained from the U.S. Geological Survey (USGS), State of New Mexico, U.S. Environmental Protection Agency (EPA), and U.S. International Boundary Water Commission (IBWC). Climate data including daily air temperature and precipitation records were obtained from National Oceanographic and Atmospheric Administration (NOAA) sources. Data were obtained for the main stem channel and tributary streams from the headwaters of the Rio Grande in south-central Colorado to Fort Quitman, Texas. Time-series data was variable for each study location, and ranged from January 1, 1975 to September 30, 2001. The database contains information for more than 1,500 water quality collection locations in the project area. Over 38,000 records of water quality data are stored in the database for over 80 physical and chemical water quality variables. In addition, 797,756 mean daily stream discharge data were loaded for selected gages throughout the project area.

4.2.1 Database Tables

Data loaded from federal and state systems were stored in tables containing individual records for each sampling date within the 1975 to 2001 time series. To ensure that data were organized appropriately, the database was designed to store data in tables that are normalized at a reasonable level. For this project, we use the term “normalize” to refer to the elimination of redundant or repetitive data. In addition, the term applies to the organization of related data stored in separate tables that can be tied together with other data sets by a logical matching field or characteristic. For example, water quality and stream discharge data are stored in separate tables. Each dataset is, in turn, related by the date and location where the measurements were collected. By relating each table to one another by date and location, the database is able to organize data in separate tables, while enabling information from these tables to be compared with one another.

4.2.2 Database Queries

The second stage of development was to create a series of queries, or requests for the database to gather and display information from a defined set of data. Queries of all data were selected by the user to be sorted and filtered. In addition, queries can combine information from one or more separate tables. For example, to examine the relationship between stream discharge and water temperature or any other combination of variables, a query could be designed to gather the necessary information from the two individual tables that store water quality data and stream discharge data separately.

4.3 Considerations for Model Input Parameters

Air temperature data were used as an input parameter for the models used to estimate each alternative’s effects on surface water quality. Data were obtained from stations that are part of the National Oceanic and Atmospheric Administration (NOAA) and National Weather Service (NWS) Co-operative Observer’s Program (Co-op). Given the spatial distribution of the Co-op stations throughout the project area, not all locations are close to USGS stream gages selected for model development. As a result, data were applied from a neighboring Co-op station for stream gages that did not share a location with a Co-op station (Table M-9).

Table M-9 portrays historical climate data obtained from the National Oceanic and Atmospheric Administration (NOAA). Data are listed according to USGS Station ID and corresponding station name. Based on their location within the project area, USGS stream gages were paired with a NOAA Co-op climate station. NOAA Co-op station identification numbers and corresponding co-op gage names are included for those locations where data were collected from the period indicated by the “begin” and end “dates”. Shaded rows (gray) mark those locations where climate data were not available. At those gages that do not have a paired co-op station, climate data from the closes climate station were applied (e.g. Socorro climate data were applied for the San Acacia stream gages).

Regression equations were devised based on two constants and the NOAA air temperature data from the gage closest to the unknown gages. The regression equation used is:

NOAA air temperature (for gage without data) = $K_1 + K_2$ * (NOAA Gage air temperature)

Where: K_1 and K_2 are constants and NOAA Gage air temperature is the air temperature at the closest gage on the day or time requested. The regression constant values (K_1 and K_2) are listed for gages with air temperatures. R^2 values are also listed for the regressions. See table M-10 for constant values.

Table M-9. Historical NOAA climatic data

USGS Station ID	USGS Station Name	NOAA Co-op ID	NOAA Co-op Gage Name	Begin	End
8251500	RIO GRANDE NEAR LOBATOS, CO	055322-5	Manassa	1975	2003
8276500	RIO GRANDE BLW TAOS JUNCTION BRIDGE NR TAOS, NM		Applied Manassa Data		
8286500	RIO CHAMA ABOVE ABIQUIU RE, NM	290041-2	Abiquiu Dam	1975	2003
8287000	RIO CHAMA BL ABIQUIU DAM, NM	290041-2	Abiquiu Dam	1975	2003
8290000	RIO CHAMA NEAR CHAMITA, NM		Applied Abiquiu Data		
8313000	RIO GRANDE AT OTOWI BRIDGE, NM		Applied Abiquiu Data		
8319000	RIO GRANDE AT SAN FELIPE, NM		Applied Albuquerque Data		
8329000	JEMEZ RIVER BELOW JEMEZ CANYON DAM, NM		Applied Albuquerque Data		
8330000	RIO GRANDE AT ALBUQUERQUE, NM	290234-5	Albuquerque Intl. Airport	1975	2003
8332010	RIO GRANDE FLOODWAY NEAR BERNARDO, NM	298387-5	Socorro	1975	2003
8354800	CONVEYANCE CHANNEL AT SAN ACACIA, NM		Applied Socorro Data		
8354900	FLOODWAY AT SAN ACACIA, NM		Applied Socorro Data		
8358300	RIO GRANDE CONVEYANCE CHANNEL AT SAN MARCIAL, NM	291138-5	Bosque Del Apache	1975	2003
8358400	RIO GRANDE FLOODWAY AT SAN MARCIAL, NM	291138-5	Bosque Del Apache	1975	2003
8361000	RIO GRANDE BELOW ELEPHANT BUTTE DAM, NM	292848-5	Elephant Butte Dam	1975	2003
8363500	RIO GRANDE AT LEASBURG DAM, NM		Applied El Paso Data		
8364000	RIO GRANDE AT EL PASO, TX	412797-5	El Paso Intl. Airport	1975	2003
8370500	RIO GRANDE AT FORT QUITMAN, TX	413266-5	Fort Hancock	1989	2003

Table M-10. Gages Without NOAA Air Temperature Data and Gages With NOAA Air Temperature Data Are Listed

Gages without data	K_1	K_2	Gages with data	R^2_{adj}
Station ID			NOAA Gage	
8276500	6.272	0.941	8251500	0.626
8290000	5.231	0.836	8287000	0.688
8313000	5.849	0.917	8287000	0.755
8319000	4.706	0.857	8287000	0.819
8329000	3.615	1.02	8287000	0.836
8354800	4.462	1.053	8332010	0.821
8354900	5.462	1.001	8332010	0.787
8363500	-1.135	1.058	8364000	0.818

4.4 Methodology

The Water Quality Team utilized linear regression models developed for selected water quality variables at locations evenly distributed throughout the Project Area to analyze potential impacts to water quality from different water management scenarios. Regression is a statistical estimation theory used to estimate the value of a variable "*Y*" for a corresponding input of "*X*". This approach uses a numerical equation to represent the statistical relationship between the input variables and the estimated result. Given the need to estimate the outcome of a particular set of conditions, regression is commonly used by federal agencies to simulate surface water quality for planning and management purposes.

Water quality, climate, and discharge data were queried from tables to create a refined dataset for model development. Given data availability (see Section #. 3.1.1), only a select number of gages were used to develop surface water quality models (Table M-11). Stream gages selected for model development are distributed throughout the project area to ensure that each stream reach would be represented during the modeling process.

Table M-11. Stream gages selected for surface water quality model development.

Section	Station Name	Gage No.
Chama	RIO CHAMA NEAR CHAMITA, NM	8290000
Chama	RIO GRANDE AT OTOWI BRIDGE, NM	8313000
Central	RIO GRANDE AT ALBUQUERQUE, NM	8330000
Central	RIO GRANDE FLOODWAY NEAR BERNARDO, NM	8332010
San Acacia	RIO GRANDE FLOODWAY AT SAN ACACIA, NM	8354900
San Acacia	RIO GRANDE FLOODWAY AT SAN MARCIAL, NM	8358400
Southern	RIO GRANDE BELOW ELEPHANT BUTTE DAM, NM	8361000

Gages are listed according to stream section, stream name, and corresponding USGS stream gage number

4.4.1 Assumptions

The following assumptions form the framework used for developing surface water quality models described in this document:

- Mean daily stream discharge, as reported by the U.S. Geological Survey, was used to develop the historical relationship between water quality variables and discharge.
- All boundary conditions except for stream discharge and air temperature were assumed constant for model development. This assumption can both overestimate and underestimate a given water quality variable because the mean daily discharge could be above or below the instantaneous conditions during which the water quality variable was sampled.
- Output data from URGWOM were used as input data for stream discharge for estimating potential effects on water quality for the 40-year sequence.
- Input data for air temperature were assigned using the historical time-series reconstruction developed for URGWOM (SSP&A 2002).

4.4.2 Regression Model Development

General linear models (GLM) were used to build linear equations to describe the effects of alternatives on surface water quality. For each linear model, correlation for a given dependent variable (e.g. water temperature) and several independent variables (e.g. discharge, air temperature, reservoir storage) was measured. The significance of models and variables were assessed using p-values at a level of alpha =0.05.

Output for each model included a numerical equation, corresponding R-square statistic, a P-value statistic for each model variable, a saved dataset for model residuals, plus all the variables in a data file for each GLM. Based on these results, individual model equations were compiled into a database table according to stream gage and water quality constituent.

Numerical models developed by the Water Quality Team are listed according to each stream gage and water quality constituent where:

- Discharge = mean daily stream discharge (cfs)
- Mean air temperature=air temperature (°C)
- Corrected air temperature=air temperature (°C) from corrected gage
- Heron Storage=storage (acre feet) in Heron Reservoir
- El Vado Storage=storage (acre feet) in El Vado Reservoir
- Abiquiu Storage=storage (acre feet) in El Vado Reservoir
- Jemez Storage=storage (acre feet) in Jemez Reservoir
- Elephant Butte Storage=storage (acre feet) in Elephant Butte Reservoir
- Galisteo Dam Gage=mean daily stream discharge (cfs) at Galisteo Creek
- Embudo Gage=mean daily stream discharge (cfs) at Embudo
- Alameda Gage=mean daily stream discharge at (cfs) North Floodway
- Rio Puerco Gage=mean daily stream discharge at (cfs) Rio Puerco
- Precipitation=mean daily precipitation (cm)

4.5 Model Performance

Of the eighteen (18) gages selected for predictive water quality model development (Table M-11), only seven (7) gages for selected water quality constituents were included in the alternatives analysis process (Table M-12). Selected gages used to evaluate alternatives based on data availability (Section #.3.1.1). The Northern Section was not selected, as conditions would not be affected by each of the seven alternatives. The water quality constituents dissolved oxygen (DO), water temperature, and total dissolved solids (TDS) are marked for each gage where the individual constituent was used as part of the Alternatives evaluation. Blank boxes indicate that a given water quality was not used to evaluate Alternatives for a given gage.

Table M-12. Gages Selected to Evaluate Alternatives

Section	Station Name	Station Name	Gage No.	DO	Water Temperature	TDS
Chama	Rio Chama near Chamita, NM	Chamita	8290000	x	x	x
Chama	Rio Grande At Otowi Bridge, NM	Otowi	8313000	x	x	x
Central	Rio Grande At Albuquerque, NM	Albuquerque	8330000		x	x
Central	Rio Grande Floodway Near Bernardo, NM	Bernardo	8332010	x	x	x
San Acacia	Rio Grande Floodway At San Acacia, NM	San Acacia	8354900	x	x	x
San Acacia	Rio Grande Floodway At San Marcial, NM	San Marcial	8358400	x	x	x
Elephant Butte-Caballo	Rio Grande Below Elephant Butte Dam, NM	Elephant Butte Dam	8361000	x	x	

Based on data availability and r-square values

Ramsey and Schafer 1997) for each model (Tables M-13a –M-13c), these seven locations exhibit the highest correlation between the dependent and independent variables used to develop the models. P-values (Ramsey and Schafer 1997) for each model input parameter were used to quantify the significance of individual model input parameters. All models used for alternatives analysis are significant at alpha=0.05, but not at the alpha=0.01 level. Independent modeling of the three selected water quality constituents was conducted by the U.S. Geological Survey (USGS). Results of USGS modeling efforts yielded similar results with little or no improvement of model fit. Original model values were deemed sufficient and were retained in final EIS analysis and reporting.

Model output was compared to historical data using the time-series reconstruction defined for the URGWOM process (SSP&A 2002). As a preliminary evaluation of model performance, this comparison illustrated whether or not the models were over or under estimating the effects of discharge on water quality constituents (Figure M-21a-g). Provided that the future 40-year sequence consists of a synthetic flow sequence using historical data re-arranged by year (SSP&A 2002), the same method was used to match historic data with a corresponding sample in the future 40-year sequence. Using this reconstruction, historical data were compared with modeled data to evaluate the performance of the model.

Table M-13a. Water Quality Models for Dissolved Oxygen (Mg/L) by Gage

Section	Station ID	Station Name	Model Parameter	Parameter Value (P-Value)	r-square	n
Chama	8290000	RIO CHAMANEAR CHAMITA, NM	Constant	12.93 (<0.0001)	0.86	93
			log[Discharge (cfs) + 1]	-0.20 (<0.0001)		
			Water Temperature	-0.20 (<0.0001)		
Chama	8313000	RIO GRANDE AT OTOWI BRIDGE, NM	Constant	14.47 (<0.0001)	0.77	186
			log[Discharge (cfs) + 1]	-0.37 (<0.0001)		
			Water Temperature	-0.20 (<0.0001)		
Central	8330000	RIO GRANDE AT ALBUQUERQUE, NM	Constant	2.68 (<0.0001)	0.74	44
			log[Discharge (cfs) + 1]	0.01 (<0.0001)		
			Water Temperature	-.22 (<0.0001)		
San Acacia	8354900	RIO GRANDE FLOODWAY AT SAN ACACIA, NM	Constant	10.90 (<0.0001)	0.74	88
			log[Discharge (cfs) + 1]	0.11 (0.13)		
			Mean Daily Temperature	-0.14 (<0.0001)		
			log [Rio Puerco Discharge (cfs) +1]	-0.16 (0.001)		
San Acacia	8358400	RIO GRANDE FLOODWAY AT SAN MARCIAL, NM	Constant	14.22 (<0.0001)	0.85	148
			log[Discharge (cfs) + 1]	0.99 (0.05)		
			Water Temp	0.98 (<0.0001)		
			log[Rio Puerco Discharge (cfs) + 1]	0.99 (<0.0001)		
Southern	8361000	RIO GRANDE BELOW ELEPHANT BUTTE DAM, NM	Constant	15.56 (<0.0001)	0.61	72
			log[Discharge (cfs) + 1]	-0.3385 (0.01)		
			Mean Daily Temperature	-0.35 (<0.0001)		

Table M-13b. Water quality models for TDS by gage

Section	Station ID	Station Name	Model Parameter	Parameter Value (P-Value)	r-square	n
Chama	8290000	RIO CHAMA NEAR CHAMITA, NM	Constant	577.47 (<0.0001)	0.60	208
			log[Discharge (cfs) + 1]	-40.77 (<0.0001)		
			Heron Storage (1000 ac-ft)	-0.23 (0.0002)		
			Abiquiu Storage (1000 ac-ft)	-0.15 (0.03)		
Chama	8313000	RIO GRANDE AT OTOWI BRIDGE, NM	Constant	906.87 (<0.0001)	0.61	264
			log[Discharge (cfs) + 1]	0.96 (0.05)		
			Heron Storage (1000 ac-ft)	-.01 (0.0001)		
			log[Embudo Discharge (cfs) + 1]	-0.17 (<0.0001)		
Central	8330000	RIO GRANDE AT ALBUQUERQUE, NM	Constant	287.26 (<0.0001)	0.41	75
			log[Discharge (cfs) + 1]	-0.01 (<0.0001)		
			Abiquiu Storage (1000 ac-ft)	-0.01 (0.07)		
			log [Galisteo Discharge (cfs) + 1]	0.09 (0.0003)		
			log [Rio Jemez Discharge (cfs) + 1]	0.94 (0.002)		
Central	8332010	RIO GRANDE FLOODWAY NEAR BERNARDO, NM	Constant	1537.63 (<0.0001)	0.73	201
			log[Discharge (cfs) + 1]	0.89 (<0.0001)		
			Mean Daily Temperature	-0.01 (<0.0001)		
			log[Embudo Discharge (cfs) + 1]	-0.11 (<0.0001)		
San Acacia	8354900	RIO GRANDE FLOODWAY AT SAN ACACIA, NM	Constant	6.07 (<0.0001)	0.54	109
			log[Discharge (cfs) + 1]	-0.01 (<0.0001)		
			log[Rio Puerco Discharge (cfs) + 1]	0.01 (<0.0001)		
San Acacia	8358400	RIO GRANDE FLOODWAY AT SAN MARCIAL, NM	Constant	1987.49 (<0.0001)	0.58	429
			log[Discharge (cfs) + 1]	0.79 (<0.0001)		
			Water Temp	0.99 (<0.0001)		
			log[Rio Puerco Discharge (cfs) + 1]	1.05 (<0.0001)		
Elephant Butte	8361000	RIO GRANDE BELOW ELEPHANT BUTTE DAM, NM	Constant	1919.85 (<0.0001)	0.59	228
			log[Discharge (cfs) + 1]	0.99 (0.03)		
			log[ElephantButte_Storage (1000 ac-ft)]	-0.24 (<0.0001)		
			Precipitation (in/day)	-0.17 (0.002)		

Table M-13c. Water quality models for water temperature by gage Water Temp (C)

Section	Station ID	Station Name	Model Parameter	Parameter Value (P-Value)	r-squared	n
Chama	8290000	RIO CHAMANEAR CHAMITA, NM	Constant	4.344 (0.0002)	0.76	197
			log[Discharge (cfs) + 1]	-0.642 (0.003)		
			Mean Daily Temperature	0.801 (<0.0001)		
			Abiquiu Storage (1000 acre-ft)	-0.009 (0.001)		
Chama	8313000	RIO GRANDE AT OTOWI BRIDGE, NM	Constant	4.53 (0.001)	0.86	290
			log[Discharge (cfs) + 1]	-0.73 (<0.0001)		
			Mean Daily Temperature	0.78 (<0.0001)		
Central	8330000	RIO GRANDE AT ALBUQUERQUE, NM	Constant	9.06 (<0.0001)	0.81	456
			log[Discharge (cfs) + 1]	-0.80 (<0.0001)		
			Mean Daily Temperature	0.68 (<0.0001)		
Central	8332010	RIO GRANDE FLOODWAY NEAR BERNARDO, NM	Constant	2.27 (0.23)	0.86	309
			log[Discharge (cfs) + 1]	-0.66 (<0.0001)		
			Mean Daily Temperature	0.79 (<0.0001)		
			Heron Storage (1000 acre-ft)	0.01 (0.03)		
			El Vado Storage (1000 acre-ft)	0.02 (0.003)		
San Acacia	8354900	RIO GRANDE FLOODWAY AT SAN ACACIA, NM	Constant	0.30 (0.71)	0.85	305
			log[Discharge (cfs) + 1]	-0.38 (<0.0001)		
			Mean Daily Temperature	0.77 (<0.0001)		
			El Vado Storage (1000 acre-ft)	0.18 (0.001)		
			log[Rio Puerco Discharge (cfs) + 1]	0.01 (0.003)		
San Acacia	8358400	RIO GRANDE FLOODWAY AT SAN MARCIAL, NM	Constant	5.741 (<0.0001)	0.78	651
			log[Discharge (cfs) + 1]	-0.33 (0.003)		
			Mean Daily Temperature	0.775 (<0.001)		
Southern	8361000	RIO GRANDE BELOW ELEPHANT BUTTE DAM, NM	Constant	15.06 (<0.0001)	0.6	280
			log[Discharge (cfs) + 1]	-0.01 (0.08)		
			Mean Daily Temperature	0.63 (<0.001)		
			log[ElephantButte_Storage (1000 ac-ft)]	-0.24 (<0.0001)		

5.0 ALTERNATIVE IMPACTS ON WATER QUALITY

5.1 Impacts on Preserving Water Quality

Reservoirs create a thermal regime similar to lakes, where the surface layer will be warmer than the river water before impoundment, and the deeper waters of the reservoir may be much cooler than the river surface water downstream. The amount of water discharged from a dam and water temperature has a synergistic affect on a number of other constituents, eventually riverine water quality begins to reflect atmospheric conditions, anthropogenic influences, and geology. Latitude and geographic location also play a prominent role, affecting water quality constituents throughout the Basin from north to south. Variations in operational management of reservoirs and dams will not only affect current water quality conditions below the dams but also conditions in the reservoirs.

Model results were weighted according to project-specific decision support software requirements. Weights were developed for water temperature, dissolved oxygen, and total dissolved solids by the WQRT for each reach and section in the project area according to data availability, model performance, and expert knowledge of water quality conditions and responses (**Table M-14**). Generally, data availability was best for water temperature and dissolved oxygen and those constituents were weighted more heavily than total dissolved solids. Weights were not developed for the entire Southern Section because of data limitations and lack of URGWOM model data. Rather, weights were only developed in the Southern Reach for dissolved oxygen and water temperature for the reach immediately downstream of Elephant Butte Dam. TDS weights were not used for this reach because of lack of suitable data for model development.

Model results were used to determine the percentage of days during the 40-year series with predicted water quality conditions that comply with water quality standards. Decision support weights were applied to the percent compliance to determine the alternatives that best preserve water quality throughout the project area. The alternative that best preserves water quality conditions was selected using model output and decision support weights after consideration was given to mitigative flexibilities that exist for reservoir storage and discharge for each alternative.

Quantitative predictive models were developed to assess indicators of water quality within the EIS. Overall model scores and rankings are indicated in Table M-14 Table M-15. Indicators included water quality constituents dissolved oxygen, surface water temperature, and total dissolved solids (TDS), and adaptive mitigation flexibility. Weighted values for each river section by criterion can be found in Figure M-22. Modeled water quality constituents were selected based on data availability. These constituents were applied to the project area, which was divided into four primary sections: the Chama, Central, San Acacia and Southern. The Chama Section combined modeled output from the Chamita and Otowi gages; the Central Section combined the Central and Bernardo gages; the San Acacia Section combined the San Acacia and San Marcial gages; and the Southern Section included only data from the Below Elephant Butte Dam gage because there was a lack of suitable historic data and modeled URGWOM data at other USGS gages below Elephant Butte Dam. The Northern Section was not selected for water quality analysis because there would be no change in operations from current conditions.

Table M-14. Water Quality Weighted Values by River Section and Criterion

Section	Criterion	Percent	Normalized	Weight
Chama	Dissolved Oxygen	12.50%	11.521	0.115207373
Central		10.00%	9.217	0.092165899
San Acacia		10.00%	9.217	0.092165899
Elephant Butte-Caballo		5.00%	4.608	0.046082949
Chama	Water Temperature	15.00%	13.825	0.138248848
Central		12.50%	11.521	0.115207373
San Acacia		12.50%	11.521	0.115207373
Elephant Butte-Caballo		5.00%	4.608	0.046082949
Chama	TDS/Conductivity	10.00%	9.217	0.092165899
Central		7.50%	6.912	0.069124424
San Acacia		7.50%	6.912	0.069124424
Elephant Butte-Caballo		0.00%	0.000	0
Conservation Flexibility		1.00%	0.922	0.00921659
		108.50%	100	

Table M-15. Overall Scores and Rankings for Water Quality

Alternative	Score	Rank
No Action	0.8792	7
Alt B	0.9627	1
Alt D	0.9415	4
Alt E	0.9419	3
Alt I1	0.9050	6
Alt I2	0.9335	5
Alt I3	0.9421	2

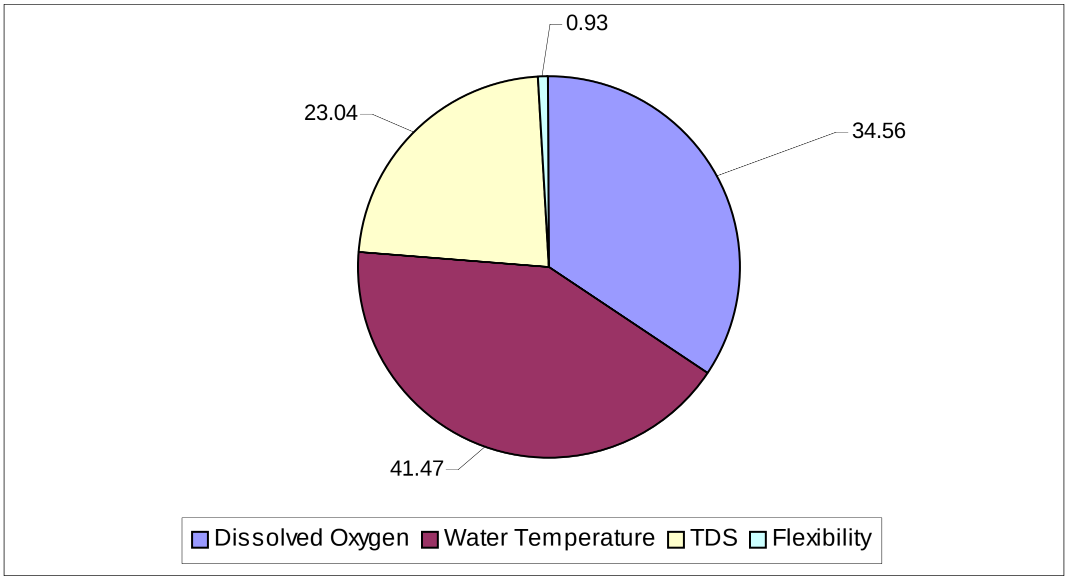

Figure M-22. Water quality model weighted values by criterion (water quality constituents).

5.2 Impacts of Future Without Action

5.2.1 Impacts on Water Quality

The modeled water quality data for the 40-year sequence were obtained using the No Action alternative as the baseline for comparison with the other alternatives. As modeled, the No Action alternative would least preserve water quality among the seven different alternatives. Adverse impacts varied by water quality constituent and river section. The current operations demonstrated support for maintaining dissolved oxygen through the four river sections. Of the modeled water quality constituents dissolved oxygen was most preserved under the No Action alternative, particularly along the Chama, San Acacia, and Elephant Butte-Caballo sections (**Figure M-23**). Dissolved oxygen is moderately affected through the Central Section under the No Action alternative. The No Action alternative is worst for preserving water temperature of the seven alternatives. Water temperature through the Chama and Elephant Butte-Caballo sections would be adversely impacted by the selection of the No Action alternative, while there would be no adverse affects on water temperature through the Central and San Acacia sections. TDS would only be affected through one river section under the No Action alternative. TDS would not be adversely affected through the Chama and Central sections, but would be adversely impacted through the San Acacia Section, particularly near San Marcial. There is no adaptive flexibility under the No Action alternative because there is no conservation storage.

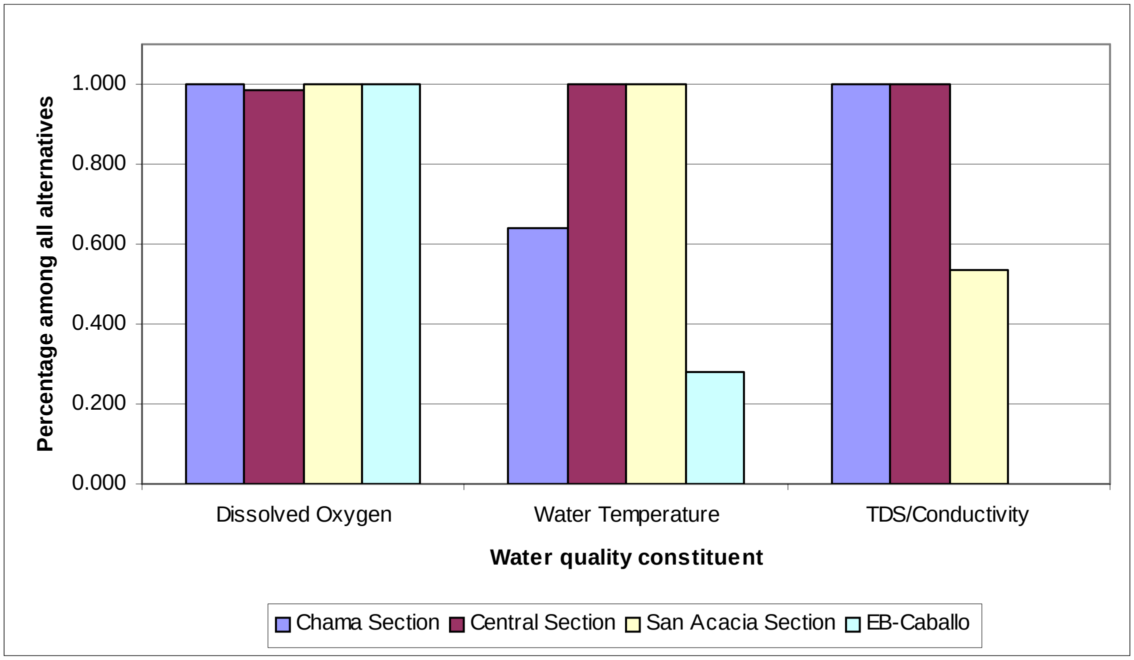

Figure M-23. Water Quality Impact - No Action Alternative

5.3 Impacts of Alternative B-3

5.3.1 Impacts on Water Quality

The modeled water quality and subsequent data matrix model showed Alternative B-3 to best preserve overall water quality in the study area. Dissolved oxygen conditions would be most adversely affected by Alternative B-3. Dissolved oxygen along the Chama and San Acacia sections would not be adversely affected by Alternative B-3, while Alternative B-3 will most adversely affect dissolved oxygen along the Central and Elephant Butte-Caballo sections. Variation among the different alternatives is relatively small though. The quality of water temperature is most preserved by Alternative B-3 within the Rio Grande system. Alternative B-3 would better preserve water temperature through the Chama and Elephant Butte-Caballo sections compared with No Action. There is no significant difference between water temperature through the Central and San Acacia sections when comparing No Action and Alternative B-3. There is no significant difference between TDS through the Chama and Central sections when comparing No Action and Alternative B-3, but there is a noticeable difference through the San Acacia Section. Alternative B-3 is the best alternative for preserving the quality of TDS in all sections, especially through the San Acacia Section. The alternative showed high levels of conservation storage compared to other alternatives, providing the most flexibility.

5.4 Impacts of Alternative D-3

5.4.1 Impacts on Water Quality

Alternative D-3 ranked fourth among the seven different alternatives for preserving water quality, performing at an intermediate level. The modeled results of Alternative D-3 closely resemble alternatives E-3 and I-3. Dissolved oxygen through the Chama and San Acacia sections would not be adversely affected by Alternative D-3. The Central Section would be moderately affected by this alternative, while the Elephant Butte-Caballo Section would be most adversely affected by selecting this alternative. No Action preserves dissolved oxygen better than Alternative D-3 through the Central and Elephant Butte-Caballo sections. Water temperature through the San Acacia and Elephant Butte-Caballo sections is not adversely affected, and is only moderately affected through the Chama and Albuquerque sections.

Alternative D-3 has a minimum affect on preserving water temperature. There is no significant difference between water temperature through the Central and San Acacia sections when comparing No Action and Alternative D-3. Alternative D-3 does preserve water temperature better than No Action through the Chama and Elephant Butte-Caballo sections. TDS is not adversely affected by D-3 through the Chama and Central sections but is moderately affected through the San Acacia Section, especially near San Marcial. Adaptive flexibility under Alternative D-3 is considered average compared to the other alternatives.

5.5 Impacts of Alternative E-3

5.5.1 Impacts on Water Quality

The modeled water quality and subsequent data matrix model showed Alternative E-3 ranked third among the seven alternatives in preserving water quality in the study area. Alternative E-3 would not affect dissolved oxygen through the Chama and San Acacia sections, while it would moderately affect dissolved oxygen through the Central Section and adversely affect values through the Elephant Butte-Caballo Section compared to other alternatives. The No Action alternative would better preserve dissolved oxygen through the Elephant Butte-Caballo Section compared to Alternative E-3. Alternative E-3 would moderately affect water temperature through the Chama, Central, and Elephant Butte-Caballo sections. This alternative would not affect water temperature through the San Acacia Section. Alternative E-3 would better preserve water temperature through the Chama and Elephant Butte-Caballo sections when compared to No Action. TDS would be preserved through the Chama and Central sections and is moderately affected through the San Acacia Section. Alternative E-3 would better preserve TDS through the San Acacia Section when compared to No Action. Adaptive flexibility under Alternative E-3 is considered average compared to the other alternatives.

5.6 Impacts of Alternative I-1

5.6.1 Impacts on Water Quality

Alternative I-1 ranked sixth for preserving water quality among the seven different alternatives. Only No Action ranked worst in preserving water quality. Dissolved oxygen through the Chama, Central, and San Acacia sections is not adversely impacted by Alternative I-1, while the Elephant Butte-Caballo Section is only moderately affected by this alternative. Dissolved oxygen would be better preserved through the Central Section by Alternative I-1 when compared to No Action, while No Action would better preserve dissolved oxygen through the Elephant Butte-Caballo Section. Dissolved oxygen would be better preserved throughout the system than five of the other alternatives. Water temperature is preserved through the Central and San Acacia sections under I-1, but is negatively affected in the Chama and Elephant Butte-Caballo sections. This alternative proved to be the second worst of the seven different alternatives in preserving water temperature. Only No Action ranked worse than Alternative I-1. TDS is not adversely affected by I-1 through the Chama and Central sections, and is moderately affected through the San Acacia Section. Alternative I-1 would better preserve TDS through the San Acacia Section when compared to No Action. Adaptive flexibility under Alternative I-1 is considered minimal, ranking second worst of the modeled alternatives. Only No Action ranks worse than Alternative I-1.

5.7 Impacts of Alternative I-2

5.7.1 Impacts on Water Quality

The modeled water quality and subsequent data matrix showed Alternative I-2 ranked fifth among the seven alternatives in preserving water quality. Alternative I-2 would not negatively affect dissolved oxygen through the Chama and San Acacia sections, while it would moderately affect dissolved oxygen through the Central Section and adversely affect values through the Elephant Butte-Caballo Section. No Action better preserves dissolved oxygen through the Elephant Butte-Caballo Section when compared to

Alternative I-2. Alternative I-2 negatively affects water temperature through the Chama Section; moderately affects water temperature through the Elephant Butte-Caballo Section; and preserves water temperature in the Central and San Acacia sections. Alternative I-2 would better preserve water temperature through the Chama and Elephant Butte-Caballo sections when compared to No Action. TDS would be preserved through the Chama and Central sections under this alternative. The San Acacia Section is moderately affected by this alternative. Alternative I-2 would better preserve TDS through the San Acacia Section when compared to No Action. Adaptive flexibility under Alternative I-2 is considered minimal, ranking third worst of the modeled alternatives. Only Alternative I-1 and No Action rank worse.

5.8 Impacts of Alternative I-3

5.8.1 Impacts on Water Quality

Alternative I-3 ranked second for preserving water quality among the seven different alternatives. Figure M-24 portrays the difference in modeled output values between alternatives B-3 and I-3. The modeled results of Alternative I-3 closely resemble alternatives D-3 and E-3. Dissolved oxygen through the Chama and San Acacia sections would not be adversely impacted by Alternative I-3, while the Central section is moderately affected and the Elephant Butte-Caballo section is adversely affected. Alternative I-3 moderately preserves dissolved oxygen throughout the system. No Action would better preserve dissolved oxygen through the Elephant Butte-Caballo Section when compared to Alternative I-3. Water temperature is preserved through the San Acacia and Elephant Butte-Caballo sections under I-3, but is moderately affected through the Chama and Central sections. This alternative proved to be the second best in preserving water temperature, and would better preserve water temperature than No Action. TDS is not adversely affected by I-3 through the Chama and Central sections. Alternative I-3 would moderately affect TDS in the San Acacia Section. TDS would be better preserved under Alternative I-3 than the No Action alternative. Adaptive flexibility is considered adequate, ranking second only to Alternative B-3 of the seven alternatives.

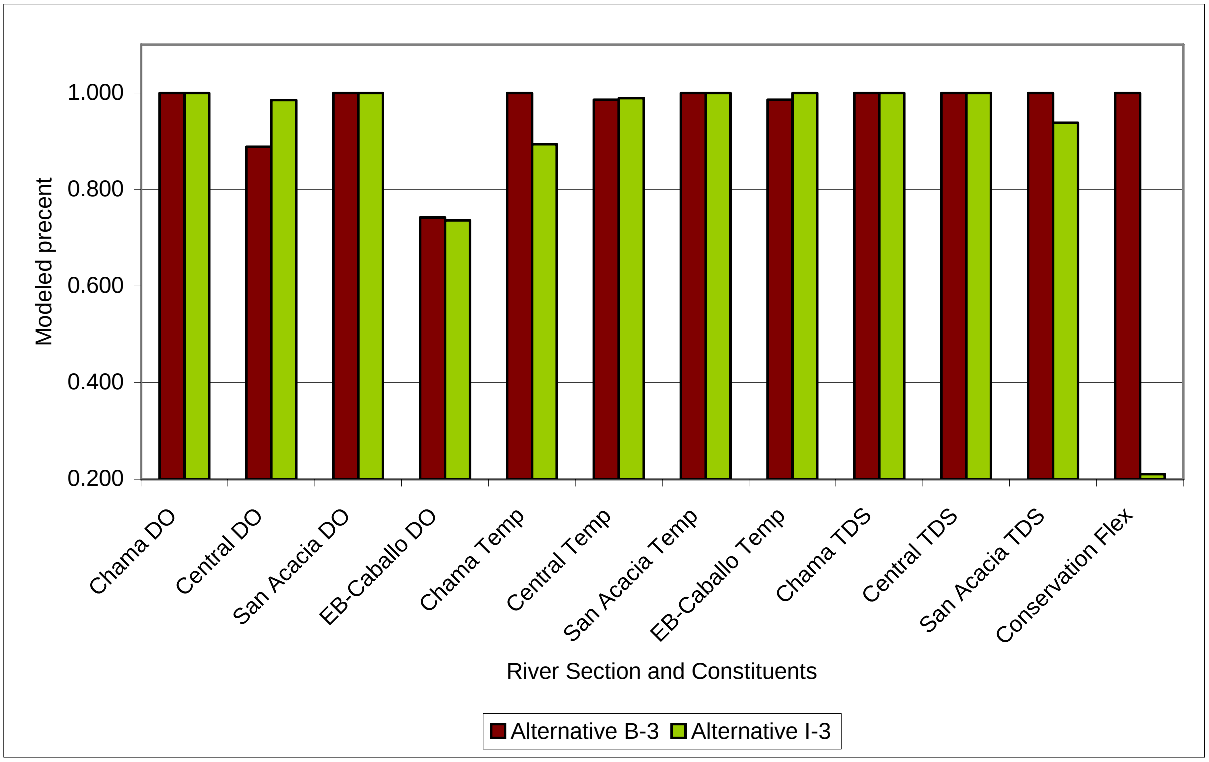

Figure M-24. A comparison of Alternative B-3 and Alternative I-3 by constituent and river section.

5.9 Comparison of Relative Impacts of All Alternatives

Many of the different operation alternatives proved to closely resemble each other following model output rankings, except for the No Action alternative which ranked seventh of seven alternatives. The three water quality constituents determined most of the criterion, although adaptive flexibility was also included in the weighted scheme. Relative impacts of all alternatives on preserving dissolved oxygen, water temperature, and TDS are listed in tables M-16a through M-16c. The No Action alternative would be most detrimental to preserving water quality in the Rio Grande Basin.

The No Action alternative has the lowest rankings for overall water temperature and TDS, and provides no mitigative flexibility. Alternative B-3 ranked first of the seven alternatives although the model indicated it would be detrimental to dissolved oxygen in the Central and Elephant Butte-Caballo sections. Dissolved oxygen through the Chama and San Acacia sections was not affected by changes in operations. Dissolved oxygen was only affected through the Central and Elephant Butte-Caballo sections by changes in operations.

Water temperature in the Rio Grande Basin would be most affected under the No Action alternative, followed by Alternative I-1. There is no affect on water temperature through the San Acacia Section under any of the operation alternatives. Alternative B-3 would best preserve water temperature of the alternatives. TDS is not affected by any of the alternatives through the Chama and Central sections, and was not modeled for the Elephant Butte-Caballo Section because of data availability. TDS would be most adversely affected by No Action, and most preserved by Alternative B-3. Similarly, adaptive flexibility is worst under No Action and best under Alternative B-3. Modeled output showed great similarities between alternatives D-3, E-3 and I-3. Alternatives D-3 and E-3 had average mitigative flexibility compared to the other alternatives, while Alternative I-1 and I-2 had poor mitigative flexibility compared to the other alternatives. The No Action alternative does not have any mitigative flexibility. Figures 25-29 illustrate the differences among the alternatives.

Table M-16a. Relative Impacts of All Alternatives on Dissolved Oxygen

Alternative	Impacts to Rio Chama Section	Impacts to Central Section	Impacts to San Acacia Section	Impacts to Elephant Butte-Caballo Section
No Action	Preserves	Minor Adverse effects	Preserves	Preserves
Alternative B-3	Preserves	Moderate adverse effects	Preserves	Significant adverse effects
Alternative D-3	Preserves	Moderate Adverse effects	Preserves	Significant adverse effects
Alternative E-3	Preserves	Minor Adverse effects	Preserves	Significant adverse effects
Alternative I-1	Preserves	Preserves	Preserves	Moderate Adverse effects
Alternative I-2	Preserves	Minor Adverse effects	Preserves	Significant adverse effects
Alternative I-3	Preserves	Minor Adverse effects	Preserves	Significant adverse effects

Table M-16b. Relative Impacts of All Alternatives on Water Temperature

Alternative	Impacts to Rio Chama Section	Impacts to Central Section	Impacts to San Acacia Section	Impacts to Elephant Butte-Caballo Section
No Action	Significant adverse effects	Preserves	Preserves	Significant adverse effects
Alternative B-3	Preserves	Moderate Adverse effects	Preserves	Moderate Adverse effects
Alternative D-3	Moderate Adverse effects	Moderate Adverse effects	Preserves	Preserves
Alternative E-3	Moderate Adverse effects	Moderate Adverse effects	Preserves	Moderate Adverse effects
Alternative I-1	Significant adverse effects	Preserves	Preserves	Significant adverse effects
Alternative I-2	Significant adverse effects	Preserves	Preserves	Moderate Adverse effects
Alternative I-3	Moderate Adverse effects	Moderate Adverse effects	Preserves	Preserves

Table M-16c. Relative Impacts of All Alternatives on TDS

Alternative	Impacts to Rio Chama Section	Impacts to Central Section	Impacts to San Acacia Section	Impacts to Elephant Butte-Caballo Section
No Action	Preserves	Preserves	Significant adverse effects	Not modeled
Alternative B-3	Preserves	Preserves	Preserves	Not modeled
Alternative D-3	Preserves	Preserves	Moderate Adverse effects	Not modeled
Alternative E-3	Preserves	Preserves	Moderate Adverse effects	Not modeled
Alternative I-1	Preserves	Preserves	Moderate Adverse effects	Not modeled
Alternative I-2	Preserves	Preserves	Moderate Adverse effects	Not modeled
Alternative I-3	Preserves	Preserves	Moderate Adverse effects	Not modeled

5.10 Preferred Alternative and Net Impacts After Mitigation

The preferred alternative for the water quality team is Alternative B-3. Alternative B-3 ranks first when compared to No Action and the other alternatives (Figure M-25). Alternative B-3 would adversely affect dissolved oxygen through the Central and Elephant Butte-Caballo sections, although adaptive flexibility would mitigate this impact. Increasing the volume of water to downstream gages would assist in raising dissolved oxygen values within the affected sections for all alternatives. The adaptive flexibility measure would also assist in mitigating the impact Alternative B-3 has on water temperature in the Central and Elephant Butte-Caballo sections. Additional flowing water would assist in stabilizing water quality, abdicating against increased water temperatures in constricted channels or isolated pools.

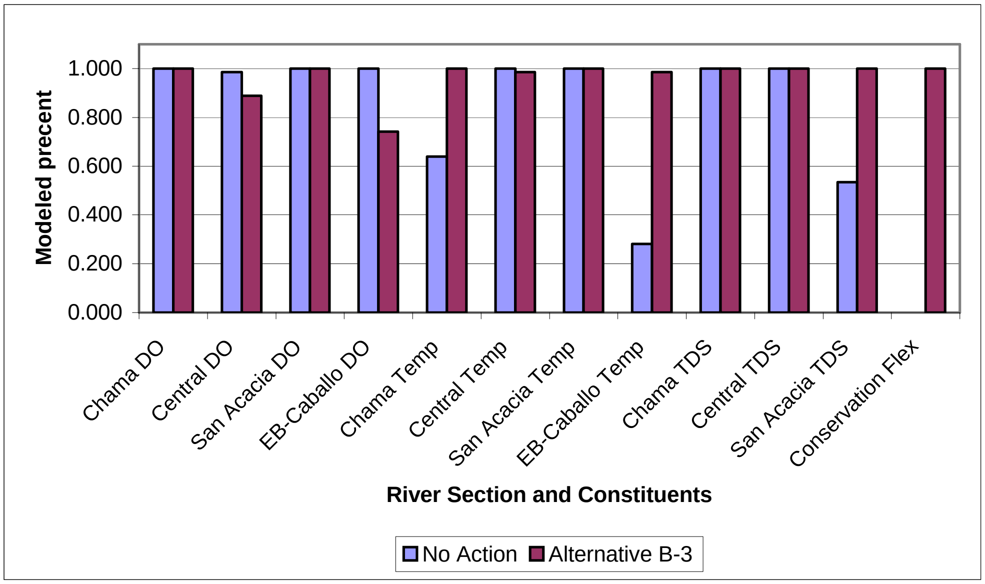

Figure M-25. A comparison of No Action and Alternative B-3 by constituent and river section.

5.10.1 Chama Section Supporting Figures

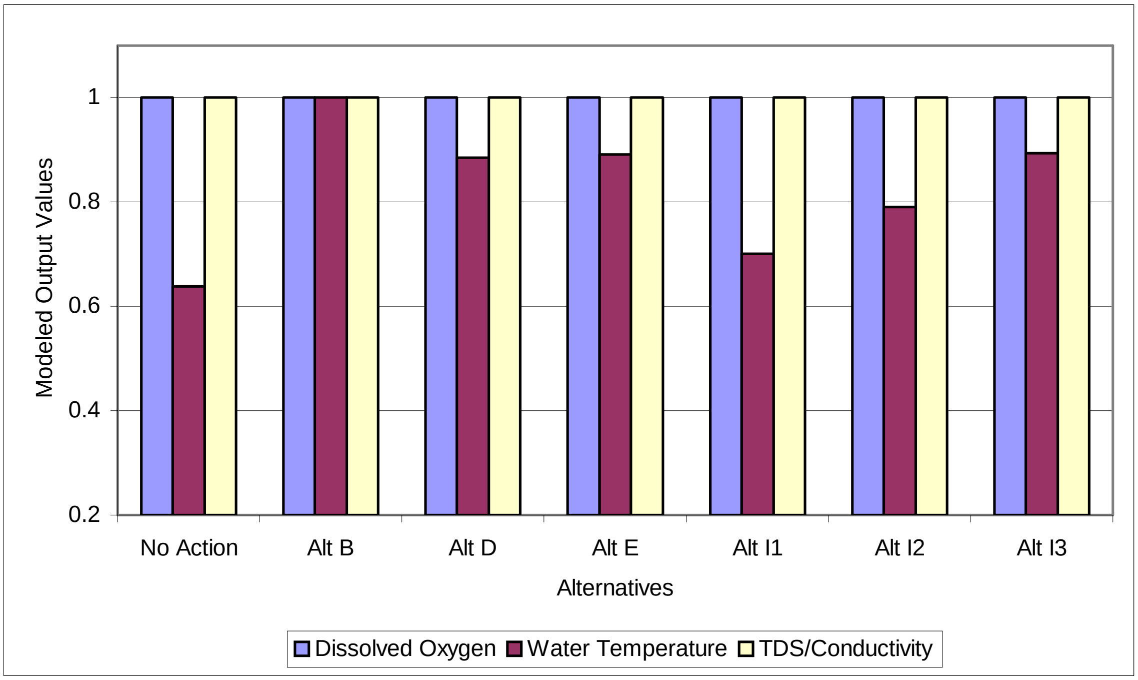

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Figure M-26. Model output Chama Section water quality by alternative and constituent

5.10.2 Central Section

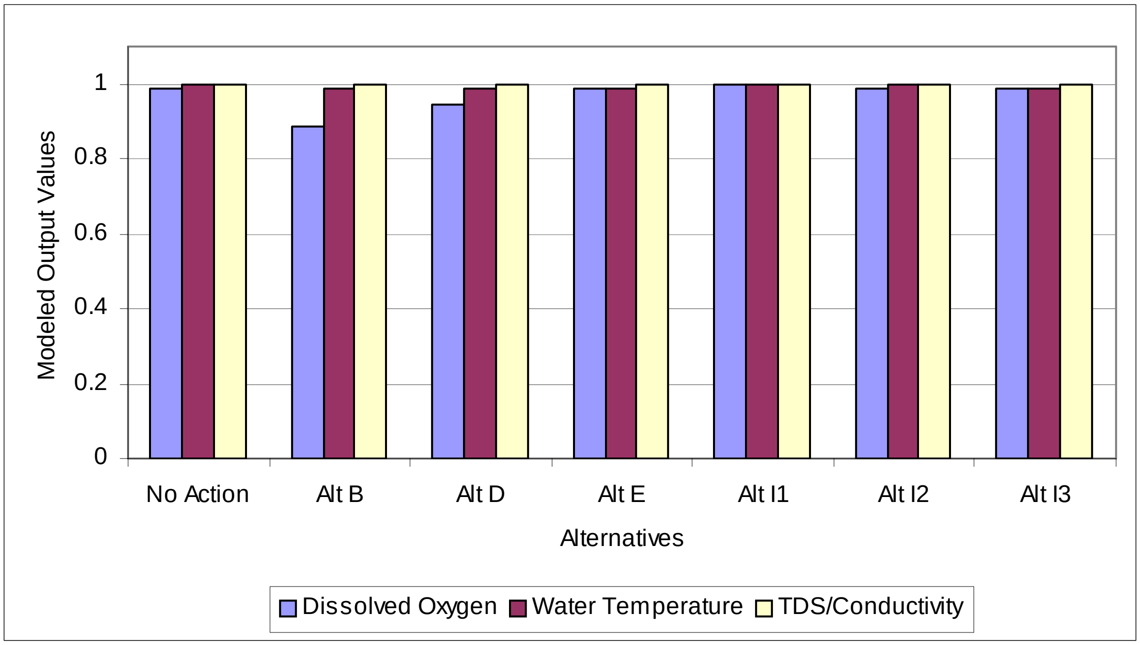

Figure M-27. Model output Chama Section water quality by alternative and constituent.

5.10.3 San Acacia Section

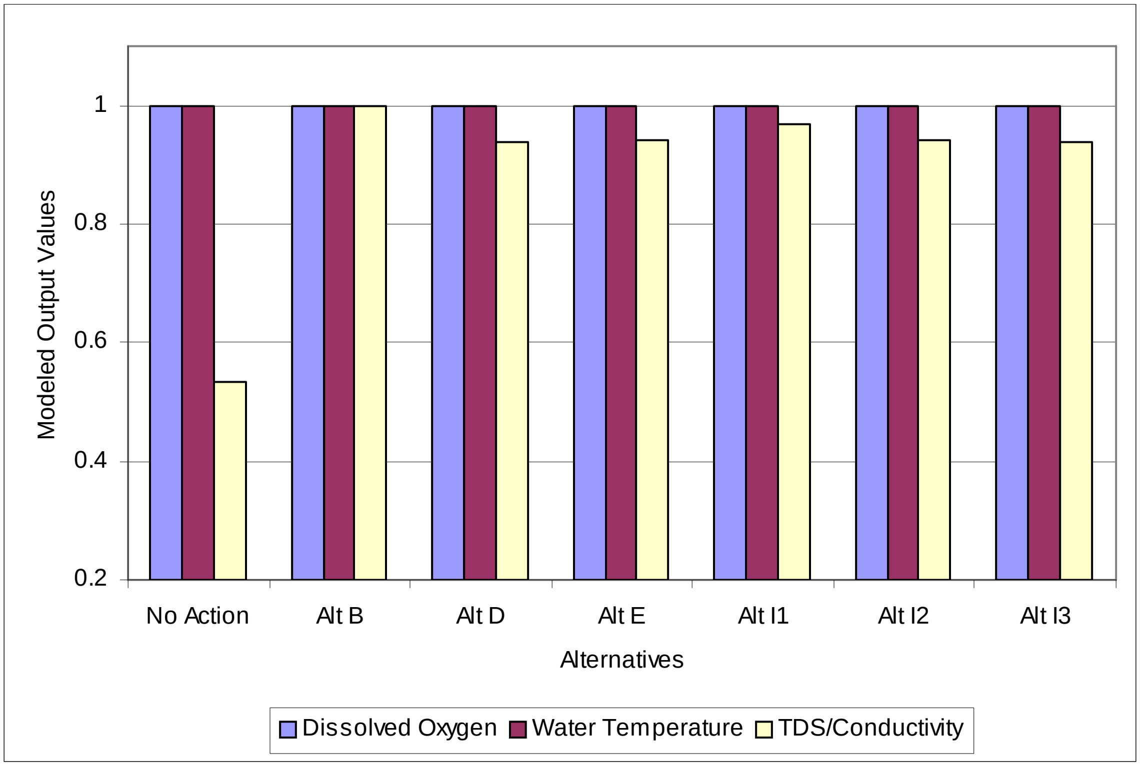

Figure M-28. Model output Chama Section water quality by alternative and constituent.

5.10.4 Elephant Butte-Caballo Section

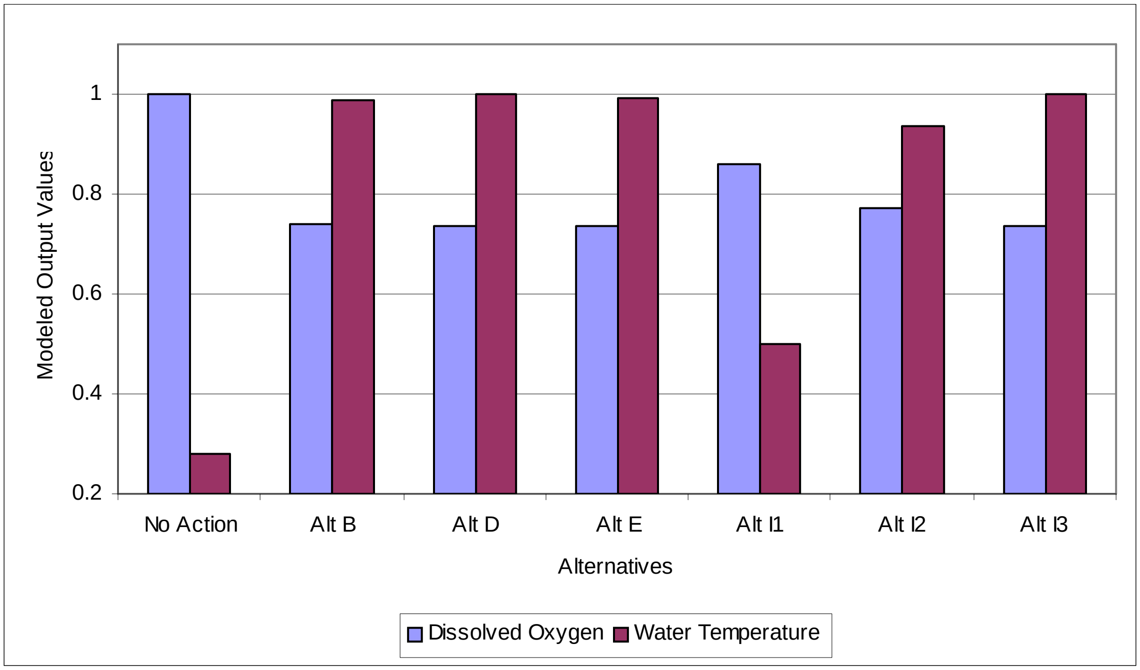

Figure M-29. Model output Chama Section water quality by alternative and constituent.

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